UTokyo

HITACHI

# Proposal

# Toward Realizing Energy Systems to Support Society5.0

(Ver.7)

April 16, 2025 Hitachi-UTokyo Lab

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# Executive Summary

Since 2016, the Hitachi-UTokyo Lab Energy Project has been presenting proposals of visions and scenarios for energy systems.

Version 6, published in 2024, focused on three key points: the changing global landscape, energy systems incorporating social and industrial transformation, and regional contributions toward achieving energy S+3E[1] and balancing energy supply and demand. By analyzing the international landscape of climate, energy, and the environment, the proposal emphasized the need for an "integrated transition"—achieving energy system transformation in close coordination with other policies and social factors. As part of the ideal vision for future energy systems, the proposal reevaluated energy scenarios in response to rising ICT demand, such as the increasing energy consumption of data centers. It also examined the gap between the current state and the target energy system for 2030, discussing measures to bridge this gap. Additionally, the proposal discussed (i) implementing demand response using digital technologies to leverage regional demand adjustment potential by 2030 and (ii) environmental credits as a means for achieving a social transition that balances economic and environmental sustainability.

This document, Version 7 of the Proposal "Toward Realizing Energy Systems to Support Society 5.0," comprehensively analyzes the changes from Version 6 and the various trends associated with those changes, discussing the issues and ways to address them.

## Chapter 2: Japan in a new phase of green transformation

Climate change, global infectious diseases, war, and rising global prices are creating a complex crisis ("polycrisis") that threatens global sustainability. In this chapter, the implications of these threats for green transformation in Japan are discussed on the basis of the recognition that at the beginning of 2025, the global situation regarding climate, energy, and the environment is entering a new phase. First, the emergence of new uncertainties related to climate, energy, and the environment is discussed from four perspectives: (i) the introduction of a new package of industrial-competitiveness policies by the European Union (EU), (ii) the sudden shift in climate and energy policy of the United States under the Trump administration, (iii) the influence of the Global South on international climate action, and (iv) the efforts of the United Nations and renowned scientists. Then, it is argued that, in Japan, it is important to aim for an integrated transition that achieves the energy transition alongside other policy priorities while taking into account social injustice and digital technologies. It is further argued that Japan must strengthen its strategic cooperation with key partners, including countries in the Global South, with which it shares interests concerning economic security, AI, and digital technology, and strive to assume its own leadership role in the sustainable development of the Asia-Pacific region.

## Chapter 3: The ideal path for the transition toward sustainable energy systems

As a result of reviewing future energy supply and demand in light of the increasing demand for electricity in the ICT sector, including data centers, the following measures are necessary to achieve the CN scenario by 2030: (1) securing decarbonized power sources, including accelerating the introduction of renewable energy (increasing solar power generation by 88 GW and wind power generation by 15 GW) and operating all existing nuclear power plants, (2) avoiding the mass disposal of PV and solving installation environmental issues, (3) operating hydrogen and ammonia power generation exceeding 10 GW, (4) the use of heat from fossil fuel power generation through cogeneration, etc., and (5) the need to ensure energy resilience and security in the event of rare occurrences such as prolonged periods of calm weather and cloud cover, fuel shortages, and disasters. In addition, we should develop and invest in innovation in the following areas in the period from 2040 to 2050: (1) further increase in CN power sources such as solar, wind, and nuclear power; (2) practical application and dissemination of $CO_2$ capture using DAC; and (3) production of synthetic fuels from captured $CO_2$ and their use in the transportation and industrial sectors. Furthermore, we considered the issues and countermeasures for the core system in response to the rapid expansion of renewable energy deployment based on the discussions in the 5th Edition of the Recommendations.

## Chapter 4: Regional contributions to balancing CN and S+3E in energy supply and demand

In the sixth version of the proposal (published in 2024), we introduced a coordination and control platform that enables creating regional value through smart energy use while providing adjustment capacity to the bulk power grid, case studies demonstrating how digital technologies can be used to enhance local renewable energy production and consumption, and examples of negative emission initiatives that leverage regional characteristics.

In this version, we re-evaluate the role expected of local communities and present insights on integrated regional energy transitions that balance economic growth and sustainability based on that role, demonstrations of how existing technologies can be used to create adjustment capacity, and policy recommendations to accelerate contributions to energy demand and supply balance. We also highlight the importance of revitalizing local economies and developing human resources alongside the contributions to S+3E in energy supply and demand, emphasizing the significance of driving social transition from the regional level.

## 14 key recommendations for realizing energy systems that support Society 5.0.

Considering the evolving landscape of energy transition in FY2024, Version 7 builds upon the 17 proposals outlined in Version 6, refining and reorganizing them into 14 updated recommendations.

## Short Term

### Chapter 2: Japan in a new phase of green transformation

1. Implement policies that turn the climate, energy, and environmental crises into opportunities for integrated transitions and work with diverse actors to promote the transformation of social systems.
2. Establishing transformative governance through funding, talent development, and scientific review
3. Accelerating transition through energy optimization and innovation driven by the integration of AI, digital technologies, and existing energy systems.
4. Strengthening strategic partnerships in climate, energy, and the environment to demonstrate leadership in the Asia-Pacific region in a multipolar environment.

### Chapter 3: The ideal path for the transition toward sustainable energy systems

5. Review of energy scenarios in light of future cost burden
6. Investment in innovation that bridges the backcasting and forecasting gaps in energy systems
7. Advancing the design of resilient medium- to long-term institutions and market frameworks alongside short-term market mechanisms
8. Restructuring the electricity market and integrating environmental value markets
9. Building a social system through regional and consumer participation

### Chapter 4: Regional contributions to balancing CN and S+3E in energy supply and demand

10. Regional contributions to balancing CN and S+3E in energy supply and demand
11. Implementing innovative strategies and policies to facilitate smooth regional transition
12. Objective analysis of social changes associated with CN and the formulation and trial implementation of growth strategies
13. Accelerating efforts toward nature-aligned negative emission technologies to expand and ensure transition pathways

## Medium-to-long Term

### Technical measures for energy systems (Chapters 3 and 4)

14.Countermeasure technologies for energy scenarios towards achieving CN

# Chapter 1 Introduction

In 2020, Japan declared its commitment to achieving carbon neutrality by 2050, joining over 160 countries worldwide in this pursuit. Even amidst the global pandemic, Europe has continued to advance ambitious greenhouse gas reduction policies, exemplified by initiatives such as RePowerEU. However, the Russian invasion of Ukraine in February 2022 triggered a sharp surge in fuel prices, leading to increased energy costs and price hikes for various commodities. The rapid implementation of carbon neutrality measures has exposed mismatches between technological innovation and social acceptance. For example, there is a disconnect between policies promoting the adoption of electric vehicles (EVs) and the lack of sufficient charging infrastructure. Additionally, the limited driving range of EVs does not fully align with user needs, further highlighting the gap between innovation and the infrastructure required to support it. Furthermore, in Europe, particularly in Germany, the emphasis on clean policies has led to a noticeable slowdown in economic growth. This illustrates how the push for accelerated carbon neutrality measures is also bringing underlying challenges to the forefront.

In Japan, the 7th Strategic Energy Plan was approved by the Cabinet in 2025. Building on the 2030 greenhouse gas reduction targets, the plan outlines key challenges and policy measures for achieving a balance between energy security, economic growth, and decarbonization up to 2040. The plan incorporates the following: strategies to manage uncertainties by evaluating multiple scenarios, maximizing the use of nuclear power, grid enhancements to accommodate expanded renewable energy adoption, and encouraging consumer participation in energy systems. These represent a shift from traditional energy policies, emphasizing a more flexible and diversified approach.

Hitachi-UTokyo Lab has been conducting in-depth research on transition scenarios, challenges and countermeasures for energy systems, and the role of Japan's local regions in realizing energy transition. Up to Version 6 of this proposal (published in 2024), we proactively addressed key themes anticipated in the 7th Strategic Energy Plan, including: scenario-based strategies for handling uncertainty, maximizing nuclear power utilization, grid reinforcement for expanded renewable energy adoption, and consumer engagement in energy systems. These recommendations were presented with quantitative evaluations. Version 5 (2022) focused on both short-term targets (by 2030) and long-term goals (2040–2050), outlining 18 key recommendations. In Version 6, these 18 recommendations were refined into 17, incorporating a review of the global energy and climate landscape, ICT sector energy demands, and strategies for balancing environmental sustainability with economic development at the regional level. This seventh version emphasizes the concept of "integrated transition"—the need to achieve energy transformation in close coordination with other policies and social developments. Expanding upon past research, Hitachi-UTokyo Lab has conducted an in-depth analysis of the international landscape in climate, energy, and environmental policy and broadened the scope from power systems to the overall energy system. On the basis of these findings, this proposal presents 14 updated recommendations, detailing the process that led to their formulation.

# Chapter 2 Japan in a new phase of green transformation

## 2.1 Introduction

Climate change, global infectious diseases, wars, and rising prices worldwide have created a complex crisis ("polycrisis") that threatens sustainability on a global scale and casts a dark shadow over the world in the early 2020s. Now, at the beginning of 2025, the global situation regarding climate, energy, and the environment is entering a new phase.

Up until recently, since the adoption of the 2015 Paris Agreement and the Sustainable Development Goals (SDGs), efforts by governments, corporations, and civil society—particularly in the early 2020s—had been strengthening owing to the promotion of green policies in the EU and globally. However, we are now entering a new phase of great uncertainty owing to changes in the political balance and clean industrial policy in the EU, the actions of the Trump administration in the United States, and the increasing influence of the Global South. As shown by the Planetary Boundaries study, the environmental crisis facing the Earth is not abating[2], and climate change is reaching unprecedented levels.

So what implications do these current global changes have for Japan's transition?

These complex changes in global geopolitics have led to rapid and unpredictable changes in the circumstances surrounding climate, energy, and the environment. In this Proposal, the implications for green transformation in Japan are discussed in reference to the changes in the global landscape that were the premise for the discussions at the Hitachi-UTokyo Lab's 7th Industry-Academia Collaborative Creation Forum held in January 2025 and the situation that has emerged since then.

In this chapter, it is pointed out that new uncertainties regarding the climate, energy, and clean industries are emerging in the international order in reference to (i) the introduction of a new package of industrial competitiveness policies in the EU, (ii) the sudden shift in climate and energy policies in the USA under the Trump administration, (iii) the influence of the Global South on international climate action, and (iv) the efforts of the United Nations and renowned scientists. It is then recommended that Japan should implement an "integrated transition"—namely, an energy transition implemented in conjunction with other policy priorities and in consideration of a sense of social injustice and the sustainability of digital technology.

## 2.2 Transitions of Japan and the world in 2024

### 2.2.1 Political changes in Europe

In 2024, political changes in Europe had a profound effect on the framework of climate, energy, and environmental policies. In particular, in the 2024 elections for the European Parliament, far-right parties made great strides in France and Germany, while the European Green Party, which won its highest number of seats ever in 2019, lost seats. It is argued that in those regions, which play key roles in the EU, the relative priority of climate measures has decreased owing to the implementation of measures supporting Ukraine in the Russia-Ukraine war, the immigration problem, worsening price hikes, and that opposition to existing governments has grown.[3] In contrast, in other countries, the number of seats held by the European Green Party has largely stabilized or increased, and in the UK, a Labour government with ambitious climate measures has been formed.

Against a backdrop of economic stagnation, political changes in Europe have led to a move in the EU to modify its climate framework in relation to drastic measures against rising energy prices, the innovation gap relative to the United States and China, and declining industrial competitiveness. In September 2024, Mario Draghi, former President of the European Central Bank and former Prime Minister of Italy, who has been called "the greatest central banker of our time" (by Paul Krugman), submitted to the European Commission, the policy-making and enforcement body of the EU, "The Future of European Competitiveness[4]" (commonly known as the "Draghi Report"). The Draghi Report recommended investments in renewable energy, digital technology, defense, and other areas of international competitiveness to overcome the EU's comparative disadvantage in relation to the United States and China[5].

Following the recommendations in the report, in January 2025, the European Commission announced a roadmap for Europe's economic growth, called the "European Union (EU) Competitiveness Compass,[6] " which outlines plans to narrow the innovation gap with the United States and China through investment in AI, biotechnology, and space technology to (i) promote a strategy to simultaneously decarbonize and compete through the "Clean Industry Deal" and its part called the "Affordable Energy Action Plan" and (ii) promote security and reduce excessive dependency on other countries in regard to resources, clean energy, sustainable transportation fuels, and clean technology.

Including policies for speeding up investment in clean industry, energy, and innovation, the EU Competitiveness Compass aims to (i) make business easier and faster, (ii) establish a "clean-Industry deal," (iii) create a more cyclical and resilient economy, (iv) strengthen research and innovation, (v) accelerate investment, and (vi) close skills and labor gaps through a more integrated EU market[7]. Some of the main policies are listed in Table 2.1, and further details are provided in Table A1.1 in the Appendix.

The European Commission explains that these policies will allow European companies to access an additional €470 billion through a more integrated capital market, bring annual savings of approximately €375 billion to EU companies by achieving simplification targets, and create 500,000 new jobs in the European circular-economy sector by 2030.

The Competitiveness Compass places emphasis on, for example, unleashing the economic potential of the EU by reducing barriers and deregulation among member states through unification, standardization, and simplification of digital technologies and clean industries within the EU, reducing dependence on fossil fuels from Russia, and establishing new trade partnerships.

**Table 2.1: Key policies in the EU's Competitiveness Compass**

| Aim | Policy |
|---|---|
| **Make doing business easier and faster** | • Introducing a new roadmap, the Competitiveness Compass, aimed at closing the innovation gap and improving decarbonization and safety.<br>• Complete the "single market" in key sectors to allow businesses to scale up<br>• Reduce administrative burdens and reporting requirements by at least 25% for large businesses and at least 35% for small and medium-sized businesses |
| **Establish a new "green-industry deal"** | • Propose setting an emissions-reduction target of 90% by 2040 through European climate law<br>• Invest in clean-energy infrastructure and technology<br>• Activate and expand mechanism to aggregate demand, including not only gas but also hydrogen and key raw materials. |
| **Create a more cyclical and resilient economy** | • Support the creation of market demand for secondary materials and a single market for waste through the new Circular Economy Act |
| **Improve productivity through the spread of digital technologies** | • Encourage investment in digital infrastructure to improve access to safe, fast, and reliable connectivity<br>• Ensure seamless and large-scale data sharing through the European Data Union Strategy |
| **Strengthen research and innovation** | • Increase research spending to focus on strategic priorities<br>• Expand "European Research Council" and "European Innovation Council" |
| **Accelerate investment** | • Propose risk-absorbing measures to make it easier for commercial banks, investors, and venture capitalists to fund fast-growing companies |
| **Close skills and labor gaps** | • Establish the "Skills Coalition" to focus on investment, lifelong learning, and skills retention<br>• Promote vocational education and training through the European Vocational Education and Training (VET) Strategy |

Source: European Commission. n.d. "A New Plan for Europe's Sustainable Prosperity and Competitiveness," https://commission.europa.eu/priorities-2024-2029/competitiveness_en, accessed March 5, 2025.

In the EU's Clean Industry Deal, measures include promoting clean energy, creating an interconnected energy market within the EU, increasing demand for EU products through the Industrial Decarbonization Promotion Act, supporting clean manufacturing, providing an aggregation mechanism for critical raw materials, diversifying supply chains extending outside the region, promoting quality jobs. The main initiatives in this regard are presented in Table 2.2 and in more detail in the Appendix.

**Table 2.2 Main items of the Clean Industrial Deal**

| Item | Details |
|---|---|
| **Low-cost energy** | • Accelerate the deployment of clean energy and promote electrification; complete the internal energy market with physical interconnections; use energy more efficiently and reduce reliance on imported fossil fuels. |
| **Promote demand for "clean" products** | • Through the Industrial Decarbonisation Accelerator Act, boost demand for EU-made "clean" products by introducing sustainability, resilience, and "Made in Europe" standards into public and private procurement. |
| **Clean-transition finance** | • Through the "Clean Industrial Deal," mobilize more than €100 billion to support EU-made clean manufacturing.<br>• Adopt the new "Clean Industry Pact State Aid Framework" to accelerate renewable energy deployment, industry decarbonization, and clean-technology manufacturing capacity. |
| **Circularity and access to raw materials** | • Establish a mechanism that allows European companies to come together and aggregate demand for critical raw materials.<br>• Establish the "EU Center of Excellence for Critical Raw Materials" to purchase raw materials jointly on behalf of interested companies. |
| **Action on a global scale** | • Diversify supply chains and build mutually beneficial trade through the "Clean Trade and Investment Partnership." |
| **Skills and quality employment** | • Launch the "Skills Coalition" to invest in workers, develop skills, and create quality jobs.<br>• Reduce bureaucracy, leverage the size of the single market, promote quality jobs, and coordinate policies at EU and national level. |

Source: European Commission. 2025. "Clean Industrial Deal," https://commission.europa.eu/topics/eu-competitiveness/clean-industrial-deal_en, accessed March 3, 2025.

European Commission President Ursala von der Leyen stated, "Our values will not change, but we must change the way we act to defend them in a changing world[8]." In line with that statement, the EU will continue to pursue the European Green Deal policies that have been pursued over the past five years, it will increase emphasis on linking these policies to improving the EU's competitiveness. The European Commission's strategic framework may be subject to revision in the future when it is voted on by the European Parliament or agreed upon by the EU Council; however, the EU's policies starkly contrast with the policy shift concerning climate action by the United States, which will be discussed below.

## 2.2.2 New system in the US

In the United States, following the presidential election in November 2024 and the subsequent inauguration of Donald J. Trump in January 2025, a rapid shift in policies regarding climate, energy, and the environment is being implemented by the second Trump administration. Upon taking office on January 20, 2025, President Trump declared a "National Energy Emergency[9]" and ordered a pause and review of all spending sanctioned by the Biden administration under the Inflation Reduction Act (IRA) and the Infrastructure Investment and Jobs Act (IIJA), and in doing so, he ended the previous administration's "Green New Deal[10]." This policy shift is going to affect the leasing and permitting of wind-energy projects and the development of infrastructure related to clean energy and electric vehicles. In contrast, the Trump administration ordered an immediate review of regulations, orders, and policies that impede the development of oil, natural gas, coal, hydroelectric, biofuels, critical minerals, and nuclear energy resources in the United States. It also directed the prompt reopening of applications for approval of exports of liquefied natural gas (Table 2.3).

Furthermore, President Trump is pushing for the U.S to withdraw—once again—from the Paris Agreement under the United Nations Framework Convention on Climate Change[11] and for large-scale layoffs of federal employees at the Environmental Protection Agency (EPA)[12] . As suggested by the above-described executive order of National Energy Emergency, future moves by the Trump administration are expected to include corporate disclosure and the repeal or relaxation of regulations on methane and greenhouse gas emissions from industry and automobiles[13].

While touting an "America First" slogan, the Trump administration has begun imposing tariffs on neighboring allies such as Mexico and Canada, as well as on China, with which the United States has close economic ties, with the aim of promoting domestic manufacturing and correcting trade imbalances[14]. These tariffs are expected to affect supply chains not only for gas and oil but also for solar panels, storage batteries, electric vehicles, and wind turbines[15], and these effects will create tensions and instability to the energy, resource, and manufacturing sectors in which investment has been made to counter climate change[16].

Moreover, it is worth noting that as of March 2025, President Trump's America is in serious conflict with European member states of the North Atlantic Treaty Organization (NATO) over how to support Ukraine in the Russia-Ukraine War. The United States has maintained stable alliances with Europe based on shared values in regard to human rights and peace; however, in the security field as well, the Trump administration is significantly shifting its attitude away from Western values and cooperative frameworks.

As explained in the next section, this shift in attitude by the Trump administration means that the influence of major powers in non-Western regions and the international networks they form will increase in regard to global politics related to climate, energy, and the environment, and that increased non-Western influence may destabilize the situation in connection with economic blocs and security issues.

**Table 2.3: President Trump's initiatives as announced by the White House (as of March 4, 2025)**

- Declares a "national energy emergency."
- Intends to make the United States the world's largest net exporter of natural gas.
- Establishes a "National Energy Governance Council."
- Repeals all of the Biden Administration's pro-China, anti-American energy regulations.
- Ends the Green New Deal.
- Withdraws from the Paris Agreement.
- Suspends federal permits for large-scale wind farms.
- Repeals regulations that impede the development of Alaska's natural resources.
- Resumes offshore drilling (in an area of 625-million acres) banned by the Biden administration.
- Repeals Obama-era greenhouse-gas rules.
- Ends the Biden Administration's suspension of export permits for liquefied natural gas (LNG) while approving the first LNG project since the ban was enacted.

Source: White House. 2025. "President Trump is Unleashing American Energy," March 4, https://www.whitehouse.gov/articles/2025/03/president-trump-is-unleashing-american-energy /, accessed March 4, 2025.
Note: Created by Hitachi-UTokyo Lab (based on the White House announcement on March 4, 2025)

### 2.2.3 Influence of the Global South

Countries in the Global South are becoming increasingly important in global efforts related to climate, energy, and the environment; however, the political and economic turmoil that has arisen since the COVID-19 pandemic and the Russia-Ukraine war, the formation of blocs, and the sudden change in policy of the United States are expected to exacerbate global polarization even further.

These countries are home to the majority of the world's population and are expected to continue to experience increasing energy demand and greenhouse-gas emissions. The region also contains the majority of natural resources (including critical minerals), forests, and biodiversity. Despite having low greenhouse gas emissions, however, many Global South countries are facing rising sea levels, higher temperatures, water scarcity, and biodiversity loss owing to climate change.

These circumstances have led to a backlash against the global energy transition led by Western countries, the UN, and other organizations, which Global South countries say will exacerbate inequalities and bring economic hardship. These countries are thus calling for changes to global climate finance and development aid, and they are have acquired crucial influence on climate change and political norms.

The BRICS Summit held in Kazan, Russia in October 2024 demonstrated once again that the BRICS are continuing to expand their influence while increasing their membership and cooperation even after the Russia-Ukraine war[17]. The BRICS, an international cooperation network consisting of Brazil, Russia, India, China, South Africa, and other countries, added the United Arab Emirates (UAE), Iran, Egypt, and Ethiopia to its membership in January 2024[18]. The nine member countries of BRICS account for 26% of the world economy and 45% of the world's population. Russian President Vladimir Putin expressed his view that a "multipolar world" is taking shape and that emphasis should be placed on "strengthening ties with BRICS, a group of countries from the Global South and Global East." The BRICS Summit statement called for greater representation of developing countries in international organizations. As of October 2024, 30 countries, including Thailand, have expressed interest in joining BRICS.

At the G20 held in Rio de Janeiro, Brazil in November 2024, it was confirmed that climate-change measures would be strengthened while taking into account the voices of the Global South[19]. It was confirmed that the G20 shares the responsibility to promote sustainable and inclusive growth, and it will work to support developing countries in particular in achieving the SDGs. It was also emphasized that it is necessary to accelerate the energy transition in accordance with the Paris Agreement and to provide financing to developing countries to support it.

The meeting declared that the G20 would strengthen—among other things—additional tools and mechanisms to reduce inequalities, call for international cooperation to promote sustainable development, and support low- and middle-income countries through cooperation on development and mobilization of resources[20]. It should be noted the African Union has now officially joined the G20 in a manner that also demonstrates the growing importance of the Global South.

With the inauguration of the Trump administration in January 2025, the United States will stop participating in climate-change measures, and that action is expected to strengthen the influence of China, which is proactive in such measures and has close ties with Asia, Africa, and Latin America[21]. China has become a key player in clean industries, such as solar, wind turbines, and electric vehicles, as well as in digital technologies such as AI, and it is beginning to play a leading role in global climate and energy policies.

However, this cooperation in the Global South is also leading to the growing influence of countries that are in serious conflict with the democratic and security frameworks of the West. The supply chains of raw materials and industries related to clean energy are rapidly being restructured in relation to economic security. North-South inequities regarding climate change, which significantly influence climate and energy measures, are being linked to the formation of security and trade blocs, and they are destabilizing European and United States-centered frameworks.

While Japan borders countries that could pose a security threat, it is expected that Japan will play a unique role in cooperating with these multipolar networks and forming a clean and stable energy supply chain.


**Figure 2.1 G20 Summit in Rio de Janeiro**
Source: G20. 2024. "Cimeira do G20," November 19, https://www.g20.rio/media-pt/cimeira-do-g20, accessed March 11, 2025.

## 2.2.4 Climate change, scientific organizations, and international organizations

It should be pointed out that even as countries around the world rapidly adjust their policies to ensure economic growth and security amid this "multipolarization" of global politics and economies, reductions of global carbon emissions are still far from a science-based path to net zero, and the devastating effects of this discrepancy are already being felt. According to the World Meteorological Organization (WMO), 2024 has been confirmed as the warmest year in the world's recorded history. It has been shown that 2024 is on track to be the first year in which the global average temperature will be more than 1.5°C above the 1850-1900 average. In particular, 2024 was a year of exceptionally high land, sea-surface, and ocean temperatures[22].

Furthermore, a report titled "The State of the World's Children 2024," published in 2024 by the United Nations International Children's Emergency Fund (UNICEF), predicted that children in 2050 will be "dramatically more likely to be exposed to the dangers of extreme climate change" compared to those in 2000, and it predicted that children will be approximately eight times more likely to be exposed to extreme heat waves, for example[23].

At COP29 in November 2024, Sandrine Dixon-Declève of the Club of Rome, Professor Johan Rockström of the Potsdam Institute for Climate Impact Research, former UN Secretary-General Ban Ki-moon, and others submitted a signed open letter to the Executive Secretary of the United Nations Framework Convention on Climate Change calling for reform of the COP process. The letter points out that while the climate-change framework has set out a scientifically rigorous and economically sound path, global greenhouse-gas emissions continue to increase and huge climate costs were still being incurred in 2023, and it argues that fundamental reform of the COP is necessary. Specifically, to ensure that each country's commitment to scientific emission targets is realized, it is proposed that the COP should become a "solution-oriented multi-stakeholder platform" that focuses on continued ambition and "implementation"—rather than large-scale, closed negotiations—with smaller meetings divided according to each topic[24].

In December 2024, the International Energy Agency (IEA) held its Global Conference on Energy and AI in France, where ministers and government officials from relevant countries, as well as executives from tech companies, discussed the sustainability of increasing energy demand due to the rapid spread of AI as well as the optimization of energy systems and the acceleration of energy innovation through AI. The IEA noted that while AI can be used to accelerate the discovery of energy resources and technologies and improve energy production, consumption, and distribution, the data centers required by AI in some regions pose major challenges to the power grid[25]. It also expressed its intention to continue addressing the opportunities and risks brought about by the relationship between digitalization and energy[26].

Moreover, at the UN Future Summit held in September 2024, the "Pact for the Future" was adopted. This pact confirmed the goal of limiting climate change to 1.5 degrees and reaffirmed the importance of multilateral cooperation. The "Global Digital Compact" included in this pact outlines comprehensive guidelines for global governance of digital technology and AI, and the "Declaration on Future Generations" agreed on the responsibility of current generations to protect the needs and interests of future generations[27].

The urgency associated with climate change and digital technology is forcing major changes to global governance frameworks and systems themselves.

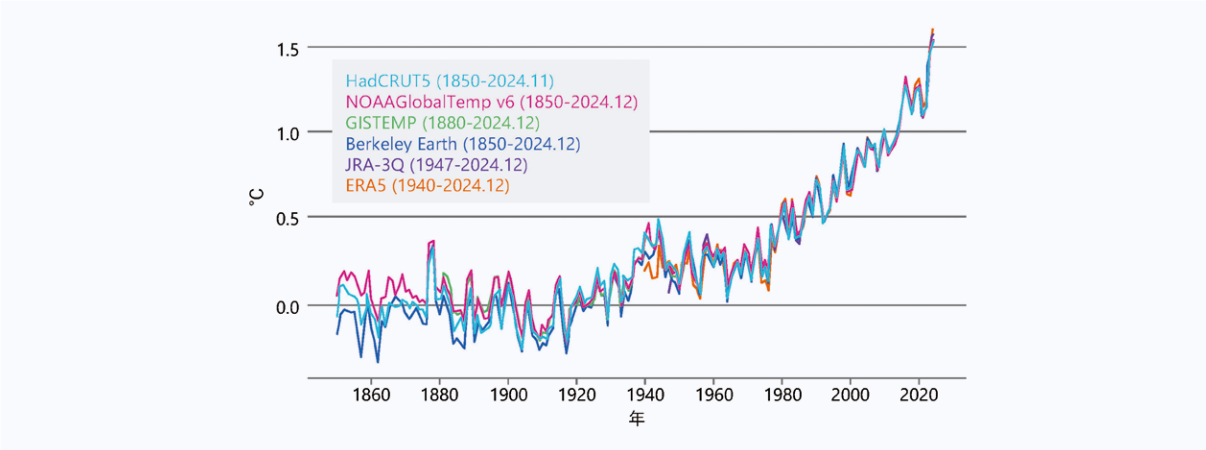


**Figure 2.2: Global average temperature: 1850-2024 (compared with 1850-1900 average)**

Source: World Meteorological Organization (WMO). 2025. "WMO confirms 2024 as warmest year on record at about 1.55° C above pre-industrial level," January 10, https://wmo.int/news/media-centre/wmo-confirms-2024-warmest-year-record-about-155degc-above-pre-industrial-level, accessed March 10, 2025.

## 2.3 For Japan's transition from 2025 to 2030

### 2.3.1 Integrated transitions and transformative governance

As explained so far, in the above-described new political climate, the EU is reframing climate measures as a matter of increasing competitiveness—rather than regulation—and aiming to introduce a new industrial-policy package. Meanwhile, the United States under the Trump administration is withdrawing from international climate measures and rapidly shifting from investment in clean energy to U.S-centered fossil-fuel energy. In this environment, the influences of China and other Global-South countries on international climate measures are growing, and, in conjunction with creating security issues, they are threatening to change the traditional Western-centered international order.

In this context, at least two challenges can be identified. As for the first challenge, a sense of social injustice and economic stagnation is generating or merging with a backlash against climate, energy, and environmental efforts. In France and Germany, economic turmoil after the start of the Russia-Ukraine war combined with migration issues to weaken the forces that promoted active green policies. In the U.S, persistent high prices and regional economic stagnation have led to a change of government and a retreat from renewable energy and climate action. Calls for a "just transition" by countries in the Global South have become an important theme in the climate-change framework.

While climate, energy, and environmental issues are of vital importance to people's lives, within traditional political frameworks in Japan, they are likely to be marginalized or separated from people's lives and considered low priority. For example, efforts related to disaster prevention and regional revitalization, which are urgent issues for the public, have tended to be treated as separate issues from efforts related to decarbonization and energy. However, these efforts are deeply connected to each other in some areas where there are policy synergies. It will be important to find an integrated path to reform that links efforts related to decarbonization of energy and industry, such as decarbonization and energy transition, with other priority policy issues.

As for the second challenge, issues related to innovation in digital technologies, including AI, are beginning to intersect with climate, energy, and the environment. While these digital technologies are useful for accelerating the energy transition by optimizing energy systems and promoting innovation, the expansion of large-scale data centers could have a detrimental impact on regional energy and water management.

In Japan, efforts related to climate, energy, and the environment have tended to be separated from efforts related to AI and digital technologies. Optimizing energy and promoting innovation in the energy sector through the maximum use of AI and digital technologies could help accelerate the energy transition while avoiding negative impacts on sustainability, such as increased electricity demand and water consumption, caused by AI and digital technologies. This indicates the need to identify areas in each field where improvements and efficiencies can be achieved through AI and digital technologies, establish clear directions for their application, and simultaneously promote the development of standardized data formats and protocols based on principles such as safety, fairness, and transparency.

In this way, it is necessary to achieve an "integrated transition" that will solve energy issues through synergistic effects with multiple policy issues while simultaneously achieving reforms that have high policy priorities. It is important to establish "transformative governance," namely, a mechanism that promotes systemic change in society itself on the basis of principles such as inclusiveness, fairness, and transparency, in conjunction with diverse stakeholders[28].

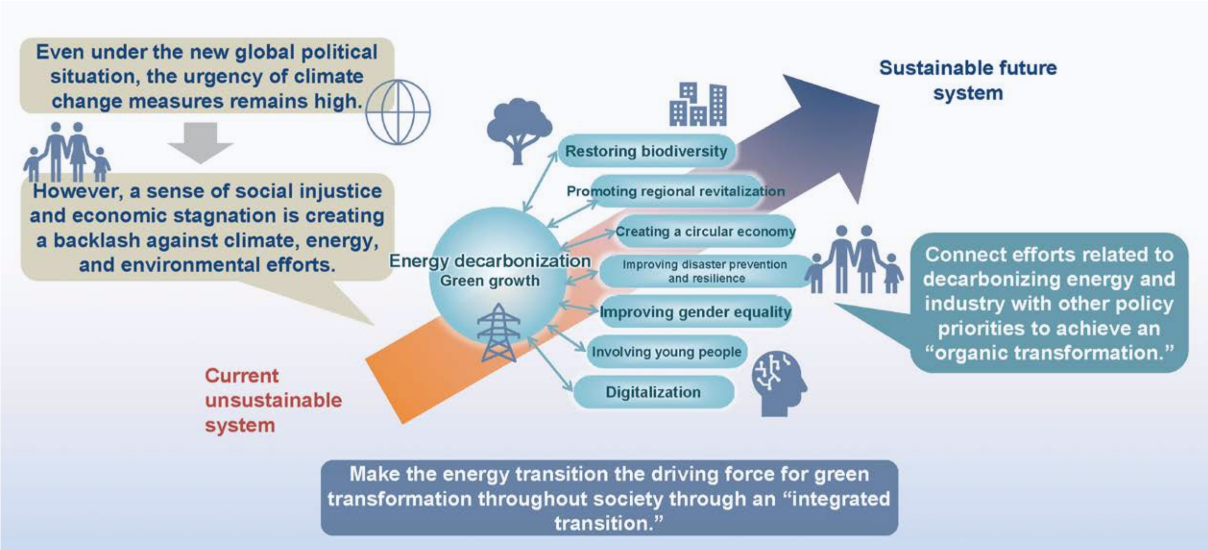


**Figure 2.3 Integrated transition**

## 2.3.2 Four recommendations for integrated transition in Japan

Based on the new conditions for green transformation described in this chapter and on the research and recommendations made by Hitachi-UTokyo Laboratory to date, the following four recommendations regarding Japan's decarbonization and GX policies are proposed.

1. Implement policies that turn the climate, energy, and environmental crises into opportunities for integrated transitions and work with diverse actors to promote the transformation of social systems.

To link the current crisis concerning climate, energy, and environment to a green transformation in Japan, in conjunction with the Energy Master Plan, GX Policy, NDCs (Nationally Determined Contributions), and a comprehensive set of other policy priorities, an "integrated transition" must be achieved. It is necessary to recognize the interconnectedness of diverse actors in Japanese society, including government, local governments, businesses, universities, and civic organizations, and to aim to create policies that promote the transformation of social systems while avoiding "lock-in" to misaligned structures.

2. Build transformative governance based on finance, human capital, capacity building, and scientific review to support the long-term transition. Make social change the foundation of the climate energy transition through inclusiveness, fairness, and transparency in decision-making.

To support long-term climate, energy and environmental transitions, it is important for governments to support the changes among industry, local governments, and other actors while emphasizing funding, human resources, capacity building[29], and scientific review. In particular, it will be important to emphasize inclusiveness, fairness, and transparency in decision-making so as to avoid giving rise to a sense of social injustice while achieving a structural shift to subsidies and green jobs in response to rising energy prices and employment changes that affect consumers. Governance that promotes such systemic change in society ("transformative governance") will be necessary as the foundation for long-term transitions.

3. Accelerating transition through energy optimization and innovation driven by the integration of AI, digital technologies, and existing energy systems. Develop strategies to reduce the energy and environmental burden of AI and digital technologies (including data centers) on the basis of scientific predictions.

It is possible to contribute to accelerating the integrated transition through AI and digital technologies, energy optimization related to climate, energy, and the environment, and promoting innovation. In Japan, it is necessary to develop software and standards that support compatibility and interoperability quickly as well as energy and data-sharing mechanisms. It is also important to find solutions based on scientific analysis regarding the impact of data centers and other AI and digital technologies on climate, energy, and the environment.

**4. Strengthening strategic partnerships in climate, energy, and the environment to demonstrate leadership in the Asia-Pacific region in a multipolar environment.**

Current global geopolitical changes are bringing about great uncertainty regarding the conditions surrounding climate, energy, and the environment. In particular, the global economic turmoil caused by the Russia-Ukraine war has led to policies to promote competitiveness in the EU, while in the United States, there has been a move—at least at the federal level—to withdraw from international climate action altogether. In this context, the influence of countries in the Global South is growing significantly and affecting multilateral cooperation and supply-chain networks.

In this new phase of green transformation, Japan needs to build on the relationships it has built so far and strengthen new strategic partnerships to promote climate, energy, and environmental transformation; at the same time, it must share interests in economic security and digital technologies such as AI. In particular, Japan needs to pursue its own leadership in sustainable development in the Asia-Pacific region while sharing commitments, funds, human resources, experience, and technology with countries in the Global South, which are beginning to play a central role in these areas.

Without the understanding of each and every citizen, it will be extremely difficult to advance Japan's green transformation through an integrated transition. It will be essential for the government to promote a vision that links climate change, energy, and environmental challenges with diverse local issues and resolves them through organic and transformative efforts and pursue this vision through inclusive dialogue and mutual support with local governments, companies, universities, and civil organizations.

## COLUMN

### From the 7th Hitachi-UTokyo Lab Industry-Academia Collaborative Creation Forum Panel Discussion Speakers (January 2025, abstracts of all remarks)

**Dr. Tshilidzi Marwala, Rector, United Nations University and UN Under-Secretary-General**

"With 2030, the target year for achieving the SDGs (Sustainable Development Goals), just five years away, unforeseen challenges are becoming apparent around the world. In response to these challenges, there are growing calls to achieve innovation through digital technology and pursue achieving the SDGs. However, while the tools and technologies required for data-driven decision-making are expected to contribute to improving efficiency, they also require large amounts of energy. To achieve the SDGs, we must re-examine our governance and mechanisms and incorporate even more digital solutions than we do now."

**Takahiro Ueno, Senior Researcher, Central Research Institute of Electric Power Industry**

"The backlash against decarbonization is due to not only conflicts between nations but also a backlash from Western society, which has been leading the way in climate-change countermeasures. For example, decarbonization policies have been implemented at the level of targets that are closely related to people's lives, such as cars and heating; as a result, the costs associated with them have become more easily recognized, and that recognition may have led to the backlash. Alternatively, the backlash could be a reflection of the divisions that already exist in society, such as anti-immigration and anti-elite sentiment. (…) I believe that the concept of an integrated transition is also important in terms of adjusting understanding and cohesion throughout society."

**Yojiro Hatakeyama, Deputy Commissioner, Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry**

"At the end of 2024, with the aim of improving the predictability of long-term investments related to GX, the "GX2040 Vision (draft)"—outlining a vision of the economy and society envisioned for around 2040—was published. In this document, the industrial structure of GX is set out as one in which new growth industries will emerge in the GX field and existing manufacturing industries will gain competitiveness by combining DX and GX. Under these circumstances, decarbonized energy holds the key to economic growth, but decarbonized-energy sources are unevenly distributed across regions. However, we do not have the time or financial means to make large-scale investments in the development of transmission lines and networks to areas of demand, so we want to advance concrete policies to promote industrial clusters by, for example, attracting corporate investment to regions with an abundance of decarbonized-energy sources and providing incentives to such companies and local governments that develop decarbonized energy sources."

## 2.4 Summary of Chapter 2

It was shown in this chapter that new uncertainties are emerging regarding climate, energy, and the environment. The uncertainties mentioned are the introduction of a new industrial-competitiveness policy package in the EU, the sudden shift in United States climate and energy policy under the Trump administration, the influence of the Global South on international climate action, and the efforts of the United Nations and scientists around the world. It is important for Japan to aim for an integrated transition that achieves the energy transition—in conjunction with implementing policy priorities—while taking into account social injustice and digital technologies. Achieving that aim requires transformative governance that shapes systemic change with diverse stakeholders in society. Furthermore, while sharing interests in economic security, AI, and digital technology, Japan is called upon to strengthen strategic cooperation in achieving climate, energy, and environmental transformation with major partners, including countries in the Global South, and to pursue its own leadership in sustainable development in the Asia-Pacific region.

- It is important to implement policies that turn the climate, energy, and environmental crises into opportunities for integrated transitions and work with diverse actors to promote the transformation of social systems.
- To support a long-term transition, it is essential to build transformative governance by combining financial resources, human talent, capacity building, and scientific review. At the same time, ensuring inclusiveness, fairness, and transparency in decision-making is crucial in making social transformation the foundation of the climate and energy transition.
- The transition must be accelerated by driving energy optimization and innovation while integrating AI and digital technologies with existing energy technologies. Also, strategies to reduce the energy and environmental impacts of AI and digital technologies, including data centers, based on scientific predictions are required.
- In this multipolar geopolitical situation, it is important to strengthen strategic partnerships in climate, energy and the environment, and to aim for leadership in the Asia-Pacific region.

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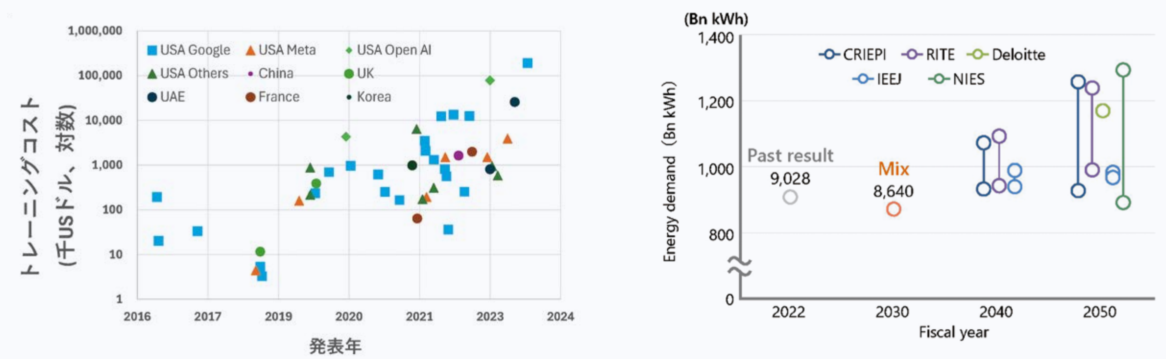
# Chapter 3 The ideal path for the transition toward sustainable energy systems

In this chapter, based on growth scenarios of the energy industry due to changes in global affairs and new innovations in the digital field since Proposal Ver. 6 was published, we review energy scenarios for realizing carbon neutrality (CN), extract new issues, and discuss their countermeasures.

## 3.1 Energy scenarios reflecting social trends and cost-conscious transitions

In this chapter, we consider whether it is possible to balance both meeting the energy supply needs of AI and data centers, expected for the growth of industries, and the transition to CN by 2050. We also consider energy balance and the issues that should be considered at the same time, as well as present countermeasures.

In recent years, the use of AI and data in industrial fields has been expanding rapidly. AI and data are being applied to business support, product development, increasing work efficiency, and creative activities such as image creation. While generative AI is expected to revolutionize a variety of fields, as shown in Figure 3.1(a), the cost required for learning using massive amounts of data (training) is increasing annually at companies such as Google and Meta. This trend suggests that the amount of needed electricity will also increase concomitantly. In Japan, considering the increase in electricity demand due to data centers and semiconductor factories, as shown in Figure 3.1(b), multiple research institutes have reported results of calculations indicating an increase in demand from 2030[30]. In particular, there is a wide range in the forecast of demand from 2040 as set by the following institutes, showing high uncertainty.




(a) AI training cost[31]

(b) Forecast of electricity demand in Japan by various research institutes

**Figure 3.1 Examples of application of AI and data to industrial fields**

A draft of Japan's 7th Strategic Energy Plan was released by the Japanese government in December 2024 to present the country's direction in responding to energy trends in 2040. Premised on ensuring safety, the plan considers it critical to make a maximal effort in increasing economic efficiency and environmental compatibility, with a stable supply of energy set as the first priority. In addition, expecting an increase in the demand for energy, the plan states that whether decarbonized energy sources can be secured directly impacts Japan's industrial competitiveness, and declares the intention to achieve a balanced energy mix that does not overly rely on specific energy sources or fuels. It also states that energy sources that contribute to energy security and have a high decarbonation effect, such as renewable energy and nuclear energy, should be maximally used (Figure 3.2).

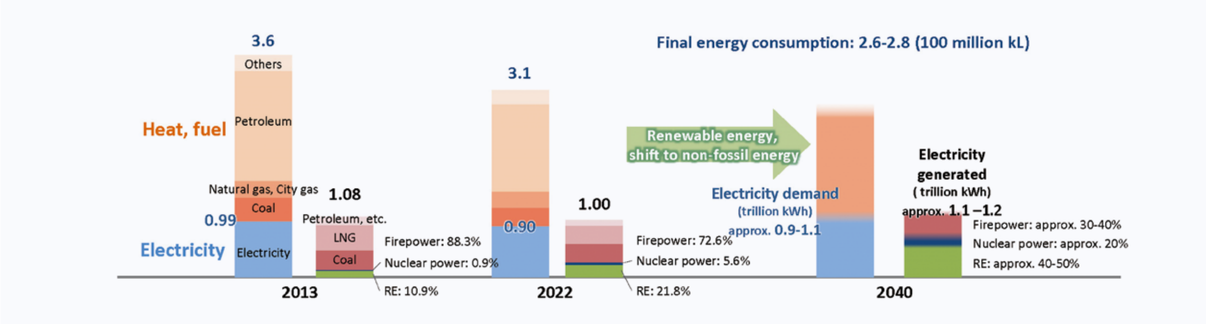
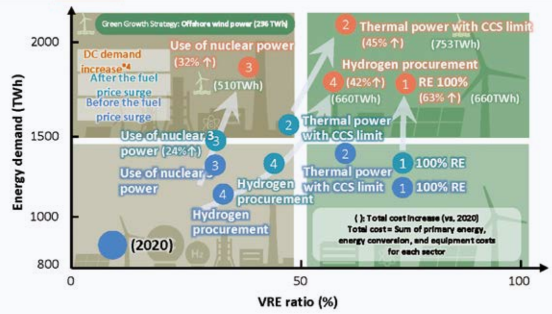



**Figure 3.2 Example of estimated effects of application of AI and data to industrial fields**[32]

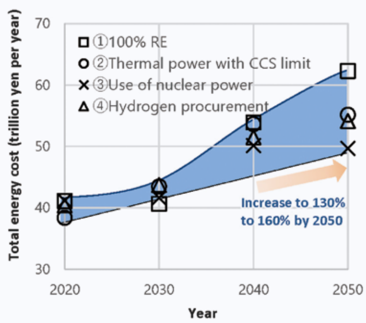
At the Hitachi-UTokyo Laboratory, we have also been using simulations to calculate energy scenarios of reaching CN in 2050. Energy mix scenarios based on the use of nuclear power, as presented in the 7th Strategic Energy Plan, is also assumed in our quantitative evaluations. As shown in Figure 3.3(a), four scenarios with different conditions (100% RE, thermal power with CCS, use of nuclear power, and procurement of hydrogen) are shown, with the vertical axis indicating energy demand in 2050 and the horizontal axis indicating VRE (e.g., solar power, wind power) as a percentage of total energy. When the increase in energy demand by data centers is taken into account, it is estimated that the energy demand will greatly increase in all scenarios. In addition to the increase in energy demand, data centers are also expected to bring about a rise in total energy costs. As the use of data centers continues, it is important to evaluate whether the social benefits of data center ICT use are commensurate with energy use and costs.

Figure 3.3(a) also shows the shift in total energy costs by year until CN is achieved.

The total energy costs comprise the total of primary energy, energy conversion, and the facility costs of each sector. Even if various technological innovations are incorporated, such as demand response and the application of technological innovations to the adjustment of supply and demand for distributed resources, we predict that total energy costs will increase to at least 130% to 160% of 2020 costs by 2050.




(a) Increase in energy demand and VRE for each scenario[33]




(b) Estimated value of total energy costs

**Figure 3.3 Estimated total energy costs associated with increase in demand**

Figure 3.4 shows an example of the increase in total energy costs if the technological innovations mentioned above are not implemented and the adjustment of supply and demand for distributed resources is not applied. In such a case, an increase in cost until 2040 from 1.5 trillion yen annually in the nuclear power utilization scenario to 2.2 trillion yen annually in the 100% RE scenario is expected. The scenarios are expected to further increase by 4 – 10 trillion yen annually by 2050. The range of cost increases varies greatly depending on the scenario. As the results show, developing a variety of technological innovations and implementing them is critical for total energy costs.

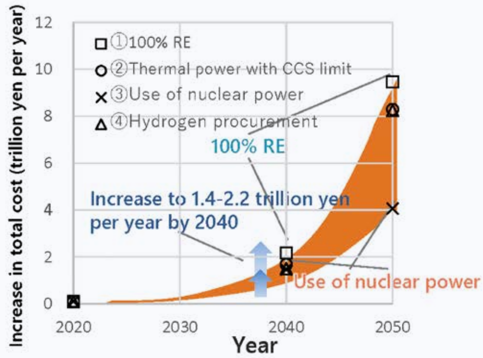



Figure 3.4 Holding down total energy costs through technological innovation (spread of demand adjustment)

To implement such technological innovations in society at the right time, initial seed investments are necessary. For investments connected to CN and also carrying business risks, the use of support frameworks such as sustainable finance and transition finance are considered to be effective. For energy systems, developing a framework of sustainable transition to CN is critical. This framework includes a supply chain from the introduction and operation of RE to numerous consumers who use RE. It also includes risk-hedging through multi-stakeholder-involved measures, such as various flexible mechanisms for supply and demand that go beyond merely adjusting the balance of supply and demand for RE and storing electricity. At the same time, effective support for sustainable finance is also provided.

## 3.2 Effects on energy system as energy demand increases

The increase in energy demand by ICT infrastructure such as data centers in 2040 is associated with energy supply conditions significantly different from today's (Figure 3.3). In this chapter, we present the results of simulations of electrical grid congestion based on the nationwide bulk power system model developed by the Komiyama Laboratory, the University of Tokyo, and extract issues. We created a bulk power transmission model, as shown in Figure 3.5. Assuming conditions in 2040, congestion of the bulk power grid is simulated by placing 80 GW of electricity generated by offshore wind power off the coast of Akita and Hokkaido on the Sea of Japan side.

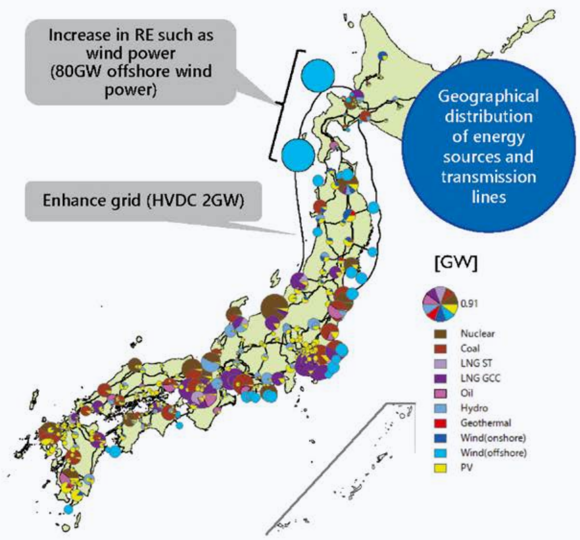
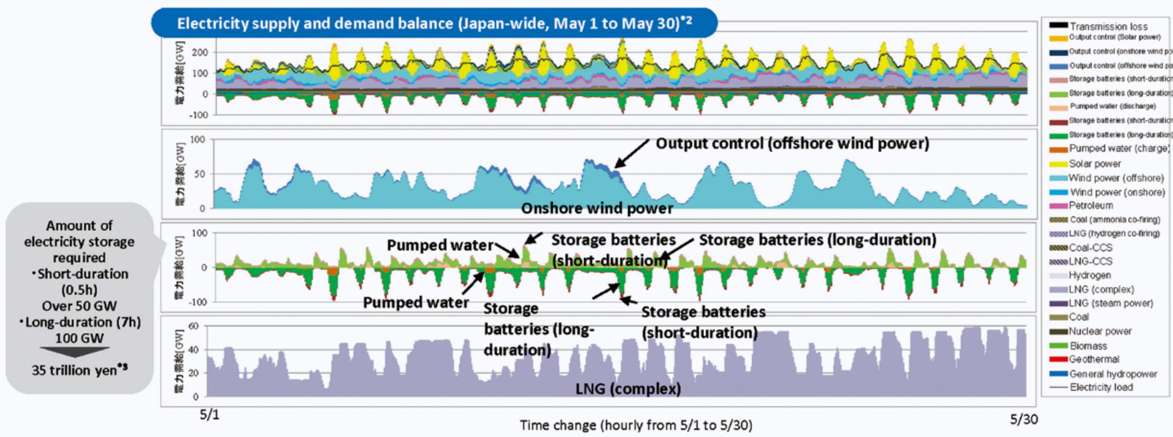



Figure 3.5 Power grid lines and distribution of energy sources in simulation of electricity congestion, taking into account the nationwide bulk power grid.

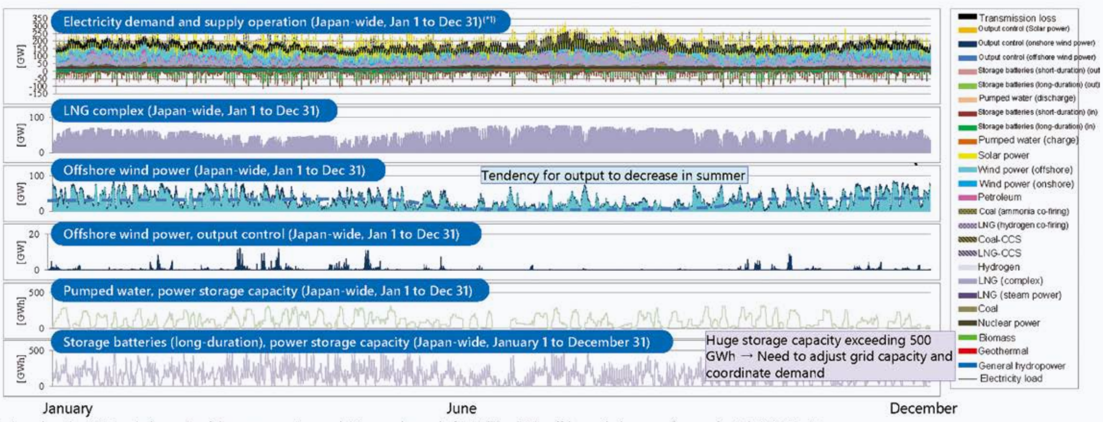
Figure 3.6 shows the balance between electricity supply and demand in May when 80 GW of offshore wind power is applied. As shown in yellow in the upper part of the figure, solar power is generated during the day. As shown in second portion of the graph, wind power generation reaches a maximum of about 50 GW. To adjust the wind and solar power generation with the demand for energy, a large amount of storage batteries is needed. To store 50 GW, short-duration storage batteries with 0.5h rated capacity are needed, and long-duration storage batteries such as NaS batteries are needed for 100 GW. The total cost of deploying these batteries is estimated to be about 35 trillion yen, requiring a separate investment about twice the size of the domestic electricity market (18 trillion yen). In addition, supply from LNG thermal power generation, which is mainly carried out during nighttime, reaches 50 GW during the hours of greatest supply. Even if wind power and solar power are deployed on a large scale, thermal power generation will continue to occupy an important position in maintaining energy supply in 2040.




*1 According to estimates by Hitachi-UTokyo Lab incorporating increased demand for ICT, 80 million kW of offshore wind power will be needed.
*2 Estimates based results of analysis using 2040 energy system model (electricity demand of 1.4 trillion kWh, offshore wind power of about 80 GW, etc.).
Note that results may change depending on the preconditions used.
*3 Estimates based on 50,000 yen per kWh.

**Figure 3.6 Electricity supply and demand in May 2040, taking offshore wind power generation into account**

Figure 3.7 shows the annual electricity demand and supply operation and corresponding power generation, such as thermal and offshore wind power. Pumped storage and storage battery operational conditions are also shown. During the summer, offshore wind power output decreases, and extra thermal power generation occurs during this time. Also, during early spring, there is reduction in wind power generation of about 10 GW. And, even when peak shifting using storage batteries is assumed, there are periods of surplus power generation.




(*1) An estimate based on the 2040 analysis results of the energy system model (power demand of 1.4 trillion kWh, offshore wind power of approximately 80 GW, etc.).
Note that the results may vary depending on the preconditions used.

**Figure 3.7 Annual electricity supply and demand situation in 2040 with offshore wind power generation taken into account**

Next, we consider regional grid flow in Akita Prefecture, where large-scale deployment offshore wind power is being carried out. Figure 3.8 shows the regional grid flow, where the shadow price (the marginal cost of transmission line capacity constraints) is positive, indicating economically rational operation. The figure shows that with large-scale deployment of offshore wind power premised on non-firm connections, there is the possibility of the regional grid's transmission line capacity being composed almost entirely of wind power generation. Therefore, for large-scale RE deployment, it is critical to take into consideration economic rationality to minimize electricity costs in plans to enhance the power grid, create adjustment capacity with storage batteries, and consider transmission line operations.

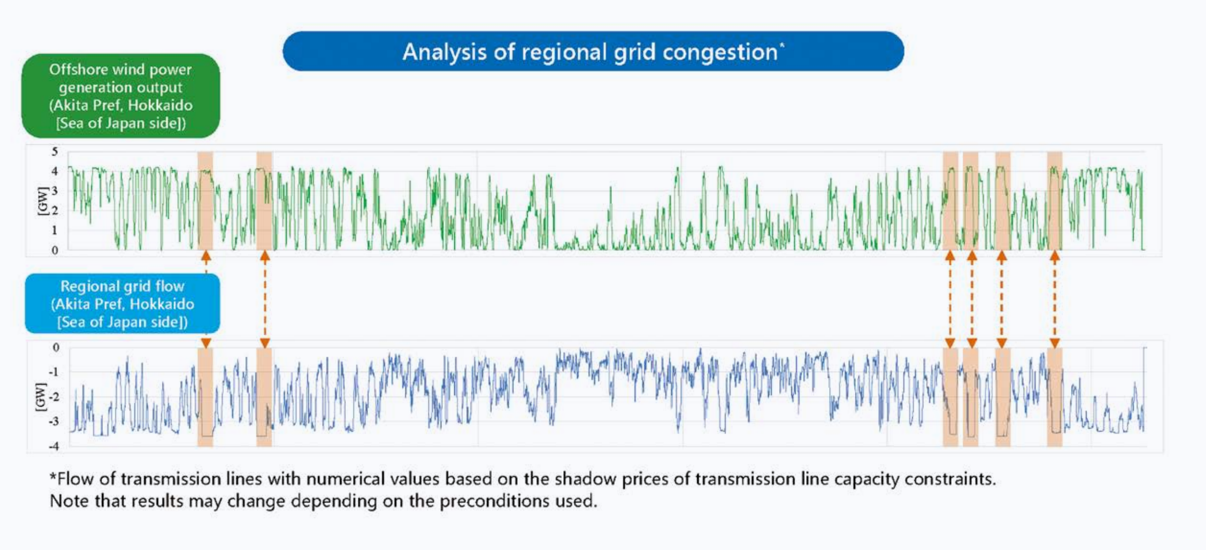



**Figure 3.8 Regional grid flow analysis**

We presented an analysis of grid congestion and flow, taking into account the expanded deployment of offshore wind power. From observing the results of operating conditions of energy sources, grid congestion conditions, and measures to avoid them, we extracted the following issues to be resolved.

- Measures based on grid enhancement plan, creation of adjustment capacity such as storage batteries, and operational conditions of transmission lines

  Regarding the expansion of RE, push-type measures premised on expanded deployment are described in the grid master plan. However, measures based on the lead time for grid enhancement are necessary. Also, with regard to operating conditions of transmission lines, it is necessary to expand deployment of RE centered on transmission lines with positively evaluated shadow prices, such as high-voltage direct current (HVDC) lines between Hokkaido and Honshu. Concerning the creation of VRE adjustment capacity, a variety of innovations that do not excessively rely on storage batteries, such as low-cost thermal storage processes, should be used. In addition, as discussed in Chapter 4, the total costs required to enhance energy systems should be reduced through, for example, the active use of consumer equipment such as heat pump water heaters. Cost-conscious measures to reduce the burden on the public should be emphasized.

- Comprehensive measures that take into account balance between energy supply and demand

  In regions supplied by RE, the power grid is expected to reach near its transmission capacity limit. It is thus necessary to formulate and implement economically rational plans for speeding up deploying RE, enhancing the power grid, and creating the adjustment capacity of batteries, etc. Because the lead time until the completion of grid enhancement is long, reforms such as moving large-scale demand to be near RE supply areas will also be necessary. There is also the possibility of placing demand for electricity by semiconductor manufacturing plants and data centers near RE supply areas. However, this depends on the development of the information industry. Predictability during the planning stage will be an issue.

- Securing stable supply of fossil fuels in the short term as well as carbon absorption and fixation in the medium to long term

  Even after RE as the main energy source is realized, from the standpoint of S+3E, the use of thermal power generation will continue. It is thus necessary to secure stable supply of fossil fuels such as LNG and develop carbon absorption and fixation technologies for CN.

# 3.3 Issues in energy system reformation and solution efforts

Japan has set an ambitious target of reducing GHG emissions by 46% by 2030 compared with 2013 levels. Achieving this target requires strengthening the country's economic structure. RE has a major role in the reduction of GHG, and energy systems have an important role in supporting the supply and demand of RE. The retail electricity business was fully liberalized in the electricity system reform of 2020, and the expansion of RE and efforts towards CN have progressed at a speed exceeding expectation. As a result of policies to increase liquidity of the wholesale electricity market, short-term outlook in the operation of electricity companies have become emphasized. The premise of power companies' business model, which involves building facilities with large amounts of investment and recovering the investment over the long term, is becoming difficult to sustain. In addition, the electricity supply-demand adjustment market, whose full-fledged operation began in 2024, continues to face insufficient bids for the offered amount. Improvements are needed in the ability by the market to adjust electricity supply and demand.

For energy system reform supporting the advancement of CN and GX, support by the creativity of power companies, which is a benefit of liberalization, is essential. At the same time, so is the development of sustainable and economically rational systems. Because competitive principles and support measures that stimulate power companies' creativity are affected by technological innovations for CN, further flexible operations while incorporating a considerable number of empirical trials as system will be needed. In addition, regarding investment in energy sources, measures such as PPAs that incorporate consumers' desire to procure RE will be used. To support these measures, the government needs to take responsibility in committing to an energy policy framework related to support fuels and power generation infrastructure, such as nuclear power and coal power.

## COLUMN

### Industry-Academia Collaboration Forum Panel Discussion, Hitachi-UTokyo Lab: Discussion of measures to encourage investment in decarbonized power sources

With Ryoichi Komiyama (Professor of the Graduate School of Engineering, the University of Tokyo) as the moderator, panelists Masahiro Chikushi (Director for Electricity Supply Policy, Agency for Natural Resources and Energy), Koichiro Ito (Professor of the University of Chicago), Hiroshi Ohashi (Vice President of the University of Tokyo), Yumiko Iwafune (Professor of the Institute of Industrial Science, the University of Tokyo), and Tatsuya Yamada (Division General Manager, Business Planning & Management Division, Hitachi) discussed the topic "Energy transition: a progressive carbon-neutral society created with the utilization of digital technology."

**Ryoichi Komiyama, Professor of the Graduate School of Engineering, the University of Tokyo:** I think that from here on, creating a business environment that encourages investment in decarbonized energy sources will become an issue of major importance. But what kind of challenges will there be when designing new systems or expanding existing ones?

**Masahiro Chikushi, Director, Electricity Infrastructure Division, Agency for Natural Resources and Energy:** I think there are two main challenges. The first is that it is difficult to predict environmental changes with a long lead time and reflect those predictions in implementation. We must consider how to manage the necessary investment and costs over the long term, from the deployment of facilities to the operation of power plants. The second challenge is that conventional power companies have been supported by power purchase agreements (PPAs). We must create an environment that makes it easier for diverse consumers and retailers that support them to enter into PPAs.

## COLUMN

**Hiroshi Ohashi, Vice President of the University of Tokyo:** When it comes to developing and maintaining facilities over the long term, how to respond when the social significance of power facilities changes is also critical. Nuclear power and coal power are representative examples. I think there are difficult aspects in advancing projects when private-sector responsibility could be suddenly questioned due to a change in the direction of discussion of disasters or global warming. Within the framework of government-private sector collaboration, if a certain stance is not maintained over the long term, then there won't be investment in the first place. There needs to be discussion on economic feasibility based on this premise.

**Koichiro Ito, Harris School of Public Policy, University of Chicago:** A factor in Chile's success is government-led PPAs. Long-term commitment was possible because the government purchased a certain amount of renewable energy. In addition, almost all renewable energy generation becoming widespread in Chile is taking place based on long-term contracts between buyers and suppliers. I think this is another example of success. So, I agree that Japan should also make greater use of PPAs.

# 3.4 Chapter 3 Summary

In this chapter, based on growth scenarios of the energy industry due to changes in global affairs and new innovations in the digital field since 2023, we review energy scenarios for realizing CN, extract new issues, and describe countermeasures. We examine the possibility of balancing the increase in energy supply needs of AI and data centers, which is expected with the growth of industries and with the transition to CN in 2050, and what issues and countermeasures should be considered along with the energy balance. For this purpose, we performed studies such as grid congestion analysis.

- The digital field, such as generative AI, shows the possibility of bringing a variety of changes to industries. Concomitantly, an increase in energy demand is expected. In the 7th Strategic Energy Plan formulated in February 2025, the total amount of energy consumed in 2040 is expected to decrease by about 30% compared to the current level. On the other hand, when it comes to electricity, its consumption is expected to increase by about 20%. At the Hitachi-UTokyo Lab, we considered multiple energy scenarios based on this increase in energy demand. In addition to an increase in the demand for energy, the total cost of increasing energy infrastructure is expected to increase to 180% from the current 130%. Cost-conscious transitions should be further reinforced.
- If technological innovations for carbon neutrality are not developed, each energy scenario will incur additional costs of 4 to 10 trillion yen by 2050. Technological innovations should be implemented appropriately based on the conditions of renewable energy expansion.
- Our grid congestion analysis, which assumes an increase in energy demand as new innovations in the digital field are implemented, revealed that the cost needed to implement 50 GW of short-duration storage batteries and 100 GW of long-duration storage batteries is about 35 trillion yen. With regard to storage battery resources, diversity in innovations to go beyond storage batteries and reduce costs should be ensured. Examples include adjustment of supply and demand using a variety of customer-side equipment and the use of electric-heat conversion systems that store electricity as heat for hot water, though, for example, heat pump water heaters.
- With regard to investment in energy sources, freedom in open trading, such as long-term decarbonization auctions and power purchase agreement (PPAs), should be increased. The formation of a system that allows consumers to actively participate in energy investment should be promoted.
- The Japanese government should clarify where responsibilities lie in the energy system, and present its long-term policy decisions.

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# Chapter 4 Regional contributions to balancing CN and S+3E in energy supply and demand

This chapter explores the role of local communities—the foundation of daily life—in achieving a balanced energy supply and demand. Section 4.1 discusses the role of regional communities from an energy supply and demand perspective. Section 4.2 outlines the key requirements for a successful social transition to enable this balance. Section 4.3 evaluates the potential contributions of regional energy transitions to S+3E, presents demonstration projects, and discusses policies necessary for real-world implementation. Section 4.4 highlights the importance of human resource development as a key regional role in achieving carbon neutrality (CN). This chapter emphasizes the need for multifaceted approaches to complex social issues and underscores the importance of fostering individuals who can tackle challenges through empathy and collaboration. Expectations for educational institutions and local governments in supporting this human resource development are also discussed.

## 4.1 The role of local communities in achieving a carbon-neutral society

To achieve a carbon-neutral society, including the transition to renewable energy as the primary power source, local communities are expected to play a key role alongside the bulk power systems, as illustrated in Figure 4.1. Communities will not only receive a stable supply of electricity and thermal energy from the bulk power system but will also contribute energy and create “adjustment capacity” by leveraging smart energy usage through data-driven demand-supply balancing. This collaborative effort will help realize a stable energy supply that aligns with the S+3E framework. Here, adjustment capacity refers to the ability to shift electricity demand over time without compromising convenience or functionality.

For Japan to achieve both economic growth and carbon neutrality, efforts from the energy demand side—not just the supply side—are essential. Efficiently utilizing limited energy resources is crucial, and the adjustment capacity generated by local communities will be a major contributing factor. Additionally, in cases where natural disasters and supply shortages disrupt the energy supply from the bulk power system, local resources such as distributed energy sources and EVs can be used to secure energy for critical regional infrastructure, such as disaster response centers.

In the sixth version of the proposal (published in 2024), we introduced:

- A coordination and control platform that facilitates smart energy use, allowing local communities to create value while contributing adjustment capacity to the bulk power grid.
- Case studies demonstrating how digital technologies can be used to enhance local renewable energy production and consumption.
- Examples of negative emission initiatives that coexist with natural restoration, leveraging regional characteristics to revitalize local economies.
- The use of environmental credits to achieve a social transition that balances economic and environmental goals. This includes maximizing local renewable energy consumption and creating a regional energy circulation system through energy cooperation.
- A blue carbon initiative that involves seaweed farming as a measure to reduce $CO_2$ storage levels.

In this version, we re-evaluate the role of local communities in the current energy landscape and present updated insights on:

- Integrated regional energy transitions that balance economic growth and sustainability.
- Demonstrations of how existing technologies can be used to create adjustment capacity.
- Policy recommendations to accelerate regional contributions to energy demand and supply balance.
- The importance of revitalizing regional economies and developing human resources in parallel with S+3E-based energy transitions.

Through these discussions, we reaffirm the critical role of local communities in driving social transformation toward carbon neutrality.

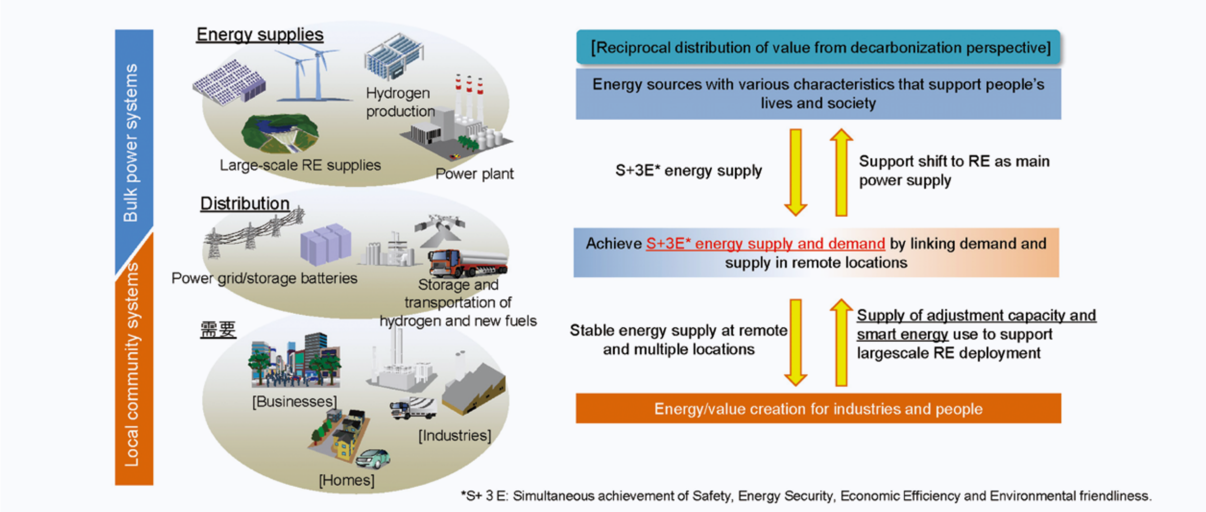



Figure 4.1 Positioning of bulk power systems and local communities

## 4.2 Energy transition driven by the regions

The 7th Strategic Energy Plan, approved by the Japanese Cabinet in February 2025, reaffirms the continued importance of energy conservation while outlining a strategy for maximizing the introduction of renewable energy and securing adjustment capacity through ongoing industrial and regional improvements, electrification, and regional collaboration. Since 2021, Hitachi-UTokyo Lab has been advocating for the practical implementation of a coordination and control platform to enable smart energy usage at the local level. In particular, we have worked to quantify and communicate the adjustment capacity potential that can be generated by local communities. The importance of locally generating this adjustment capacity has been recognized in various forums, including by the Power Generation Cost Verification Working Group organized by Japan's Agency for Natural Resources and Energy, where load-shifting strategies such as time-shifting hot water heating and EV charging have been highlighted as effective measures[34].

The coordination and control platform is designed to integrate with the bulk power system and consumer-side devices, particularly those with built-in energy storage. By leveraging device usage information and spot price data on the wholesale electricity market from the Japan Electric Power Exchange (JEPX), the platform optimizes energy consumption schedules to generate adjustment capacity without compromising convenience. This system offers dual benefits; namely, avoiding excessive investment in grid-scale battery storage for power suppliers and reducing electricity costs for energy consumers. By creating adjustment capacity, this approach enables economically viable adoption and utilization of renewable energy.

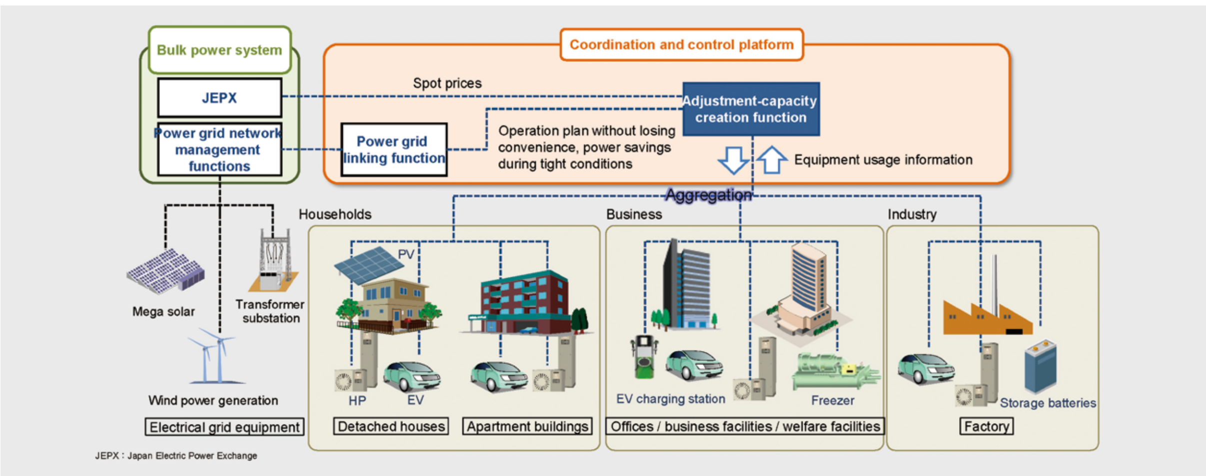



Figure 4.2 A coordination and control platform that digitally connects bulk power grid systems and consumer equipment

Many smart energy practices, such as time-shifting hot water heating with heat pumps, are already feasible using existing technologies. However, both energy providers and consumers must adapt their behavior, and these necessary changes can act as barriers to social transition. To facilitate this shift, it is crucial that local stakeholders experience tangible benefits at each stage of the transition. Moreover, the transition should be gradual and multi-faceted, ensuring continuity and safety while integrating incremental adjustments into daily life.

Figure 4.3 illustrates the envisioned transition at the local level. For individual energy consumers, this approach offers increased convenience, lower energy costs, and financial benefits from participating in the adjustment capacity market. At the regional level, smart energy usage promotes value creation through efficient energy utilization, ultimately enhancing the region's appeal and strengthening resilience. By promoting the widespread adoption of smart energy devices—such as heat pump water heaters with energy storage capabilities—and integrating them into a coordinated energy management platform, this transition can be streamlined. Such a platform will help orchestrate energy use across the community, support operational optimization, and facilitate a smooth social shift for all stakeholders.

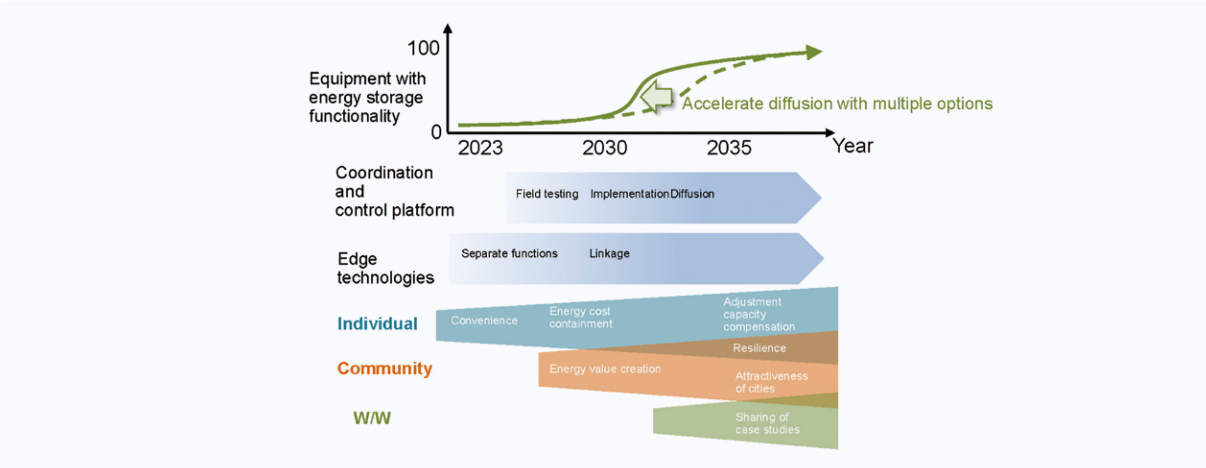



**Figure 4.3. Gradual social transition in local communities**

Digital technology plays a key role in supporting the transition outlined in Figure 4.2 by enabling the visualization and control of devices and energy usage. By making energy consumption patterns transparent, digital tools help create adjustment capacity without compromising consumer convenience, reducing complexity while enhancing demand-side flexibility. Japan has long been a leader in energy storage technologies, such as heat pump water heaters, which are recognized globally. By leveraging digital innovation, these technologies can be utilized more efficiently, enabling the cost-effective creation of adjustment capacity and maximizing the effective use of renewable energy.

Since former Prime Minister Yoshihide Suga's 2020 carbon neutrality declaration, the Japanese government has introduced several key policies, including the Green Growth Strategy and the issuance of GX transition bonds. Starting in 2024, aiming to leverage adjustment capacity of consumer equipment, Japan's Ministry of Economy, Trade and Industry (METI) has been leading discussions through the DR Ready Study Group, focusing on demand response (DR) integration for heat pump water heaters and home battery storage systems. Following these discussions, bidirectional EV chargers are expected to become the next focal point of policy deliberations. Given the product life cycles of energy devices and Japan's $CO_2$ reduction targets, there is an urgent need to accelerate the development of industry-wide standards. These include: (1) standardizing communication interfaces between devices and the grid, incorporating electricity price signals, operational status data, and control commands; and (2) establishing security guidelines to ensure safe and reliable system operation. To expedite implementation, a diverse range of ideas must be tested and demonstrated in real-world conditions, ensuring that regulatory frameworks effectively support Japan's carbon neutrality and energy transition goals.

## COLUMN

### The State of DR Ready Implementation

DR Ready refers to a state in which consumer-side devices, such as home appliances, are equipped with the capability to support demand response (DR) via remote operation over a communication network. By enabling DR-ready functionality, consumers can move away from the conventional approach of using electricity whenever and however they wish, instead contributing to the decarbonization, efficiency, and stability of the power system.

As mentioned in the main text, discussions on DR Ready implementation began in Japan in 2024. However, in the U.S., states such as Washington, Oregon, and California have already mandated that heat pump water heaters be DR-ready by state law. Similarly, in the U.K., after implementing requirements for EV chargers, policymakers are now considering mandating DR-ready functionality for heat pump water heaters as well[35]. In Japan, the cumulative number of heat pump water heaters shipped by the end of fiscal year 2022 reached 8.77 million units[36]. Given the 2030 and 2035 greenhouse gas reduction milestones and the typical replacement cycles of these devices, it is critical to accelerate the implementation of DR-ready functionality. Doing so will unlock their potential as a valuable source of adjustment capacity, supporting Japan's energy transition efforts.

| DR Ready Implementation Status | |
|---|---|
|  | Heat pump (HP) water heaters are mandated as part of appliance energy efficiency standards in Washington and Oregon, and as part of building energy efficiency standards in California. |
|  | Considering applying the same standards used for mandatory EV chargers to HP water heaters. |
|  | Developed DR functionality standards for electrical appliances and considering mandatory compliance with these standards. |
|  | Started study sessions on HP water heaters. |

4.4 Comparison of DR-Ready implementation status

# 4.3 Leveraging the potential of local communities

Looking at wholesale electricity prices in different regions on JEPX, we see instances where the minimum price of 0.01 yen/kWh is applied. While the frequency of these occurrences varies yearly, the number of regions where the price drops to 0.01 yen/kWh for over 200 hours annually is increasing (Figure 4.5). A price of 0.01 yen/kWh indicates that even in areas where renewable energy (RE) output curtailment has not been implemented, surplus RE electricity is not being effectively utilized in the market. If RE integration continues under these conditions, it could lead to excessive grid-scale battery investments, underutilized grid expansion, and increased RE curtailment, further driving up social costs. To avoid such inefficiencies, it is crucial to reflect spot prices appropriately in retail electricity pricing for consumers, thereby encouraging behavioral changes and promoting the widespread adoption of retail pricing models that reflect RE surpluses.

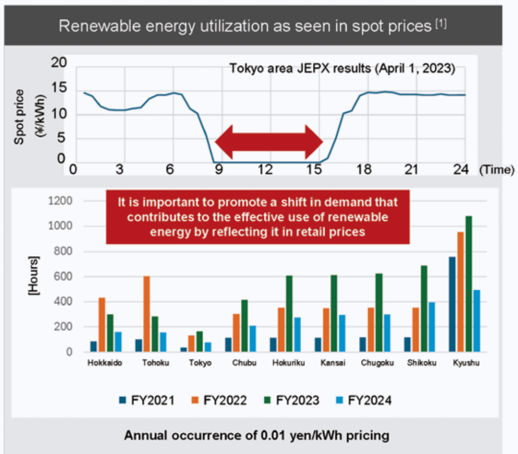



Figure 4.5 Actual spot prices and their cumulative data

Hitachi-UTokyo Lab has long recognized the potential of adjustment capacity created by local communities. Since JEPX spot prices reflect surplus RE output, we conducted a national-scale economic simulation estimating the social benefits of optimizing the operation of heat pump water heaters (HPWHs) and EVs in houses, apartment complexes, and welfare facilities based on spot price fluctuations. The findings indicate a potential annual social cost reduction of 49.3 billion yen (Figure 4.6). This simulation assumed 2030 adoption rates of HPWHs and EVs and incorporated projected spot price scenarios. Additionally, the analysis considered a scenario where effective RE utilization raises the spot price floor from 0.01 yen/kWh to 1.00 yen/kWh. For more details, refer to Appendix of Version 5 of the Policy Proposal[37].

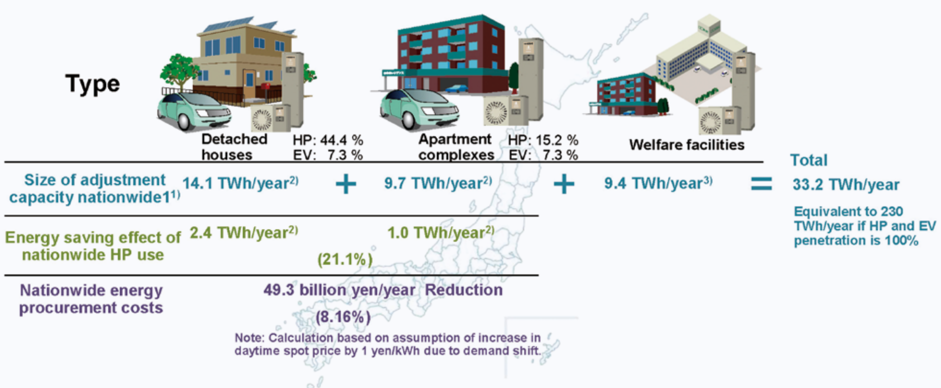



Figure 4.6 Nationwide adjustment capacity generated by local communities (taken from Ver. 5)

Furthermore, in March 2024, in addition to these simulations, we have built a test bench simulating real-world residential water heating and launched a pilot study on remote water heating control linked to JEPX Tokyo-area spot prices. This test uses commercially available HPWHs and operates without requiring a separate Home Energy Management System (HEMS). Instead, it leverages standard mobile apps provided by HPWH manufacturers for remote control. The system has already achieved over 5 months of continuous operation and accumulated 11 months of data as of February 2025.

Extrapolating the results of this pilot study nationwide—considering the current installed base of HPWHs and total households in Japan—suggests that demand-side water heating control could lead to an annual procurement cost reduction of 30 billion yen. Details on the test setup and calculation conditions can be found in the Appendix.

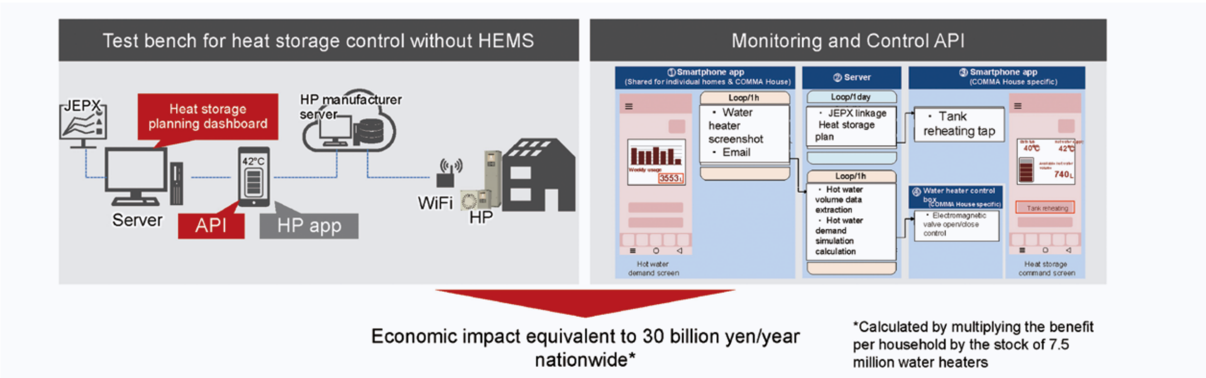



**Figure 4.7 JEPX spot price-linked heat pump water heater control test bench**[38]

## 4.4 Policies to accelerate the creation of regional adjustment capacity

The pilot study described in the previous section demonstrated that remote water heating control linked to JEPX can be implemented for heat pump water heaters without requiring individual HEMS. While this proves that existing technologies can enable smart energy use, successfully embedding adjustment capacity creation into society and accelerating its widespread adoption requires more than just technical feasibility. It is crucial that end users (consumers) receive sufficient benefits to motivate their participation in smart energy use. Two primary benefits for consumers are considered: (1) economic demand response (DR) to enable shifting electricity consumption to cheaper time periods to reduce costs; and (2) market transactions to enable receiving compensation for participating in supply and demand adjustment capacity markets. The following outlines policies to accelerate each approach.

<u>**Case (1): Economic Demand Response (DR)**</u>

To accelerate economic DR, the following two conditions must be met:

(The details are explained below.)

- i) Consumers must experience tangible benefits from shifting their energy usage to create adjustment capacity.
- ii) The necessary technologies for executing such energy shifts must be readily available.

For consumers, as the main stakeholders, to benefit from flexible energy use, retail electricity providers must offer pricing plans that reflect JEPX spot prices to users who can provide adjustment capacity. Currently, some retail electricity providers, particularly new power companies, have started offering market-linked plans and DR-based reward programs, balancing economic incentives with convenience. However, adoption remains limited due to perceived complexity and uncertainty. To address this, simplified cost estimation tools—which do not require users to input personal information—should be developed to reduce consumer hesitation and encourage broader participation.

Additionally, beyond cost savings, discussions should explore mechanisms to fairly compensate consumers who shift their energy usage not only for personal savings, but also to help suppress rising social costs.

For demand-side flexibility to scale, it is essential to minimize the need for individual configurations and ensure that price signals can drive energy use adjustments without compromising consumer convenience. Currently, inconsistencies in data access across different electricity retailers hinder smart energy management. To overcome this, industry associations—including retail electricity providers and device manufacturers—should work together to identify and address barriers that limit smart energy integration. Additionally, government support for establishing discussion forums to advance these efforts is needed. Furthermore, several supporting measures should be reinforced. These include improving data availability from network-connected devices such as EVs; enhancing measurement and storage of time-series heat demand data, alongside electricity data, to develop consumer heat demand models; and expanding subsidies and financing options to promote the adoption of heat storage technologies, such as hot water tanks and thermal storage systems, which complement HPWHs.

**Case (2): Adjustment capacity transactions**

To provide market-traded adjustment capacity from consumers, the following two conditions must be met:

- i) The predictability and reliability of the adjustment capacity must be verifiable from external sources.
- ii) The location of devices providing adjustment capacity must be known.

In adjustment capacity market transactions, certainty is more critical than in economic DR. Discussions in the DR Ready Study Group have emphasized the need to measure device status variables and establish communication interfaces (IFs) that allow external verification of predictability and reliability. To achieve this, devices must be equipped with data transmission capabilities that allow external parties to assess their predictability and reliability based on factors such as device type and operational history. Additionally, the following measures should be pursued in parallel: (1) incentivizing manufacturers to develop devices that meet these requirements and (2) establishing a device certification scheme that publicly verifies compliance with these standardized communication interfaces.

Currently, DR-ready heat pump water heaters are expected to be available for sale by 2029[39]. This means that widespread adoption will not be in time for the 2030 decarbonization goal. To maximize energy efficiency and prepare for the full-scale adoption of DR-ready devices, it is essential to actively experiment with value creation using existing devices and mature market-based energy services before DR-ready devices become widely available.

To accelerate renewable energy deployment, balancing supply and demand alone is not sufficient—it is also necessary to alleviate congestion in local grids and distribution substations. In Europe, to avoid investing in low-utilization grid assets, several countries are developing and implementing Local Flexibility Markets (LFM), where regional adjustment capacity is traded through market mechanisms. Japan could also implement LFMs to leverage local adjustment capacity and improve grid asset utilization. However, achieving this requires a database that includes the location of adjustment-capacity-providing devices, and stakeholders must urgently discuss how to build and share such data. Additionally, regional adjustment capacity could be used to support local consumption of locally produced renewable energy (RE), reducing curtailment. In such cases, policies should be developed to support mechanisms that align environmental benefits with regional economic growth, such as exemptions from RE output curtailment for locally consumed energy.

## COLUMN

### Hitachi-UTokyo Lab Industry-Academia Collaboration Forum Panel Discussion - Digital Technologies Connecting Consumer Devices and Renewable Energy

For this panel discussion, participants explored new policy frameworks and the expansion of existing systems to foster a business environment that encourages investment in decarbonized power sources, as described in the column in Chapter 3. In addition to these topics, Professor Yumiko Iwafune from the Institute of Industrial Science at the University of Tokyo presented and led discussions on digital technologies that connect consumer devices with renewable energy.

**Professor Yumiko Iwafune, Institute of Industrial Science, The University of Tokyo**

"Without sufficient incentives for stakeholders, progress will stall. To encourage the widespread adoption of spot-price-linked electricity plans, appliance manufacturers must align with retail electricity providers to develop smart electricity usage features that allow consumers to benefit from energy-efficient behavior. Currently, the price gap in spot electricity rates is largely driven by fuel cost fluctuations. However, if a system were introduced where transmission tariffs also fluctuate in response to renewable energy output, widening the price gap, it could create a transition that benefits both retail electricity providers and consumers."

# 4.5 Advancing regional transition alongside S+3E in energy supply and demand

Local communities form the foundation of people's lives, making the revitalization of local industries and population retention critical for regional sustainability. To achieve carbon neutrality while fostering regional economic growth, it is essential for communities to leverage their unique characteristics and pursue mid-term development goals. Additionally, rather than relying entirely on external support, fostering local talent capable of leading these initiatives is crucial for sustainable regional progress.

This chapter introduces blue carbon management as a successful example of balancing local industrial revitalization with carbon neutrality. Furthermore, it highlights the importance of nurturing young innovators involved in blue carbon-related projects and discusses the future of education needed to develop such talent.

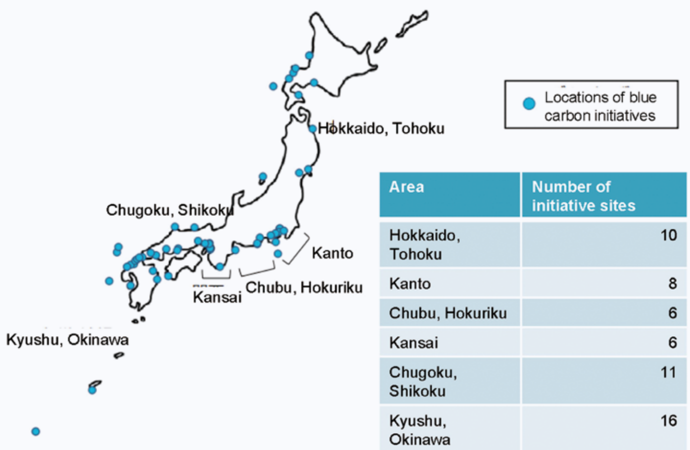
## Revitalizing local industries through blue carbon management

A region's defining characteristics extend beyond geographic location or access to energy resources. The transition to carbon neutrality presents new opportunities to enhance regional economies through environmental measures and decarbonization initiatives that leverage natural resources such as forests and oceans.

In Japan, the aging of forests has led to a decline in $CO_2$ absorption capacity, with the amount absorbed in 2022 decreasing by 6.4% compared to 2021, down to approximately 50.2 million tons. However, as an island nation surrounded by sea, Japan has a unique opportunity to utilize marine ecosystems in its decarbonization efforts. Recognizing this, Japan's Ministry of the Environment became the first in the world to officially report $CO_2$ absorption figures incorporating blue carbon from seaweed beds and other marine vegetation in 2024[40].

Currently, over 40 blue carbon initiatives are underway across Japan (Figure 4.8). These projects not only absorb $CO^2$ but also restore fishing grounds and revitalize local fisheries, making them prime examples of leveraging regional resources for sustainable growth.

Beyond blue carbon, other successful local energy solutions include biomass power generation using thinned wood, livestock waste, and food waste, contributing to local energy self-sufficiency[41]. Actively discovering and supporting innovative initiatives that connect local ecosystems and waste management to energy production is vital. To ensure their success, financial and regulatory frameworks must be strengthened to facilitate both regional industrial revitalization and carbon neutrality efforts.




| Area | Number of initiative sites |
|---|---|
| Hokkaido, Tohoku | 10 |
| Kanto | 8 |
| Chubu, Hokuriku | 6 |
| Kansai | 6 |
| Chugoku, Shikoku | 11 |
| Kyushu, Okinawa | 16 |
| Total: | 57 sites (45 cases) |

**Figure 4.8 Blue carbon initiatives in Japan**[42]

### Developing human resources and education in local communities

By analyzing and utilizing materials surrounding fisheries, forestry, and livestock industries as resources, they can contribute to both regional industrial revitalization and carbon neutrality. It is essential to foster more of such initiatives. However, generating these ideas requires individuals who can perceive social trends, identify local challenges firsthand, and possess the knowledge to address them. Without such talent embedded within local communities, even the initial formulation of innovative ideas becomes difficult.

To address this, education must expose students to a broad range of social issues and provide foundational knowledge to understand their environment. In particular, nurturing data literacy is crucial for leveraging digital technologies. As highlighted in Section 4.2, digital technology is a key enabler of smooth social transitions. However, its successful application requires individuals who can analyze, understand, and operationalize the benefits of data utilization. While AI technologies can assist in understanding data, it is equally important for individuals to cultivate a problem-solving mindset aligned with mid-term visions. The goal is to increase the number of people capable of identifying problems, communicating them broadly, analyzing complex social issues from multiple perspectives, collaborating with others, and taking actionable steps toward solutions.

Another crucial role of education is to nurture small seeds of innovation into significant advancements while fostering a sense of ambition—helping individuals realize that their actions can influence society.

For example, at the 2025 Taiwan International Science Fair, high school students from Nagano Prefecture presented their invention, the "Midori Bio Reactor," a small ball designed to absorb carbon dioxide. Their project won first place in the Biochemistry category. This invention involves the solidification of a suspension containing green algae, such as Euglena, by introducing a calcium chloride solution, resulting in a portable photosynthetic material (Figure 4.9). Supporting young innovators like these and providing opportunities for challenges and experimentation is a vital responsibility of educational institutions and local communities in fostering human resources.

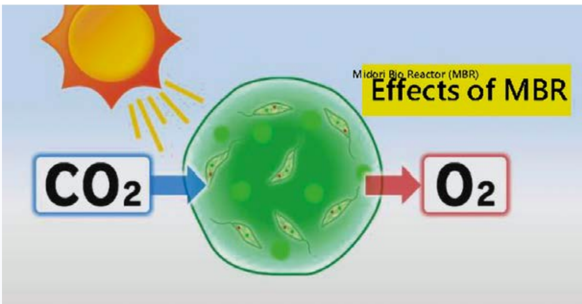



**Figure 4.9 Portable negative emission technology "Midori Bio Reactor"**[43]

## 4.6 Chapter 4 Summary

Local communities serve as both the foundation of people's lives and key players in achieving S+3E through smart energy utilization once carbon neutrality is realized.

Furthermore, under the government's 2030 greenhouse gas reduction strategy, the household and commercial sectors are expected to lead decarbonization efforts, ahead of industries where emission reductions take longer.

This chapter reassessed the potential of local communities based on empirical evidence and examined the necessary requirements and policies for an integrated regional transition. The key takeaways are as follows:

- Conditions for the transition of local communities contributing to S+3E in energy supply and demand:
  A gradual transition that realizes benefits step by step while ensuring continuity, safety, and economic viability from current lifestyles is essential. Digital technologies that enable visualization and control of consumer energy usage and devices serve as a key enabler of this transition.

- Market-based evaluation of Japan's renewable energy utilization and policy proposals:
  Using JEPX market data, this chapter examined Japan's current renewable energy utilization from a market perspective and empirically quantified the potential social value that local communities can generate under the existing framework. While initiatives such as those of the DR Ready Study Group are driving social transitions through demand-side measures, it is crucial to proactively advance efforts without waiting for their outcomes to reach the market. This includes maximizing the effective use of existing equipment, expanding the adoption of time-of-use electricity pricing plans, revising regulations to fairly reward consumers for contributing to energy coordination, and swiftly developing a database of devices capable of providing adjustment capacity.

- Fostering local talent to drive economic growth and carbon neutrality:
  Local communities must leverage their unique characteristics and align with a mid-term vision to achieve both economic growth and CN goals. Developing talent to lead this transition is crucial. Education should focus on raising awareness of social challenges, providing fundamental knowledge and data literacy to help individuals understand their environment. Encouraging innovation—nurturing small ideas into impactful solutions while instilling a sense of ambition—is key to empowering people to see their actions as catalysts for social change.

- Hitachi-UTokyo Lab's contributions and future initiatives:
  Hitachi-UTokyo Lab will continue to promote empirical research contributing to S+3E energy transitions while formulating and disseminating strategic next steps based on data and insights under a vision for the future. We will expand collaborations with industry groups to discuss demand-side contribution strategies. In addition to open forums and policy proposals, we will create opportunities for cross-generational and international exchange, thereby contributing to human resource development.

34 Agency for Natural Resources and Energy. 2024. "General Resources and Energy Investigation Committee: Power Generation Cost Verification Working Group (5th Meeting) Document 1 – Estimated Power Source Costs Considering Partial System Integration." Accessed March 6, 2025.
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35 MRI. 2024. "Regulatory Status of Demand Response for Heat Pump Water Heaters in Various Countries." Accessed March 7, 2025.
https://www.meti.go.jp/shingikai/energy_environment/dr_ready/pdf/001_05_00.pdf

36 Japan Refrigeration and Air Conditioning Industry Association (JRAIA). 2023. "41st General Resources and Energy Investigation Committee, Energy Conservation and New Energy Subcommittee, Energy Conservation Working Group: Document 5 – JRAIA's Initiatives Toward Carbon Neutrality by 2050." Accessed March 7, 2025.
https://www.meti.go.jp/shingikai/enecho/shoene_shinene/sho_energy/pdf/041_05_00.pdf

37 Hitachi-UTokyo Lab, 2023. Proposal: Toward Realizing Energy Systems to Support Society 5.0 (Version 5). Accessed March 6, 2025.
https://www.ht-lab.ducr.u-tokyo.ac.jp/wp-content/uploads/2023/07/proposal_ver5_jp_202307.pdf

38 The actual state of heat pump water heaters per 100,000 households was compiled by Hitachi-UTokyo Lab based on Smart Japan, "3rd DR Ready Study Group Session: Formulating DR Ready Requirements for Heat Pump Water Heaters as 'Upward DR' Devices."

39 Japan Refrigeration and Air Conditioning Industry Association. 2025. "DR Ready Study Group (4th Meeting) Materials." Accessed March 12, 2025.
https://www.meti.go.jp/shingikai/energy_environment/dr_ready/pdf/004_03_00.pdf

40 Ministry of the Environment, 2024. "Japan's GHG Emissions and Removals in FY 2022." Accessed March 12, 2025.
https://www.env.go.jp/press/press_03046.html

41 Ministry of Agriculture, Forestry and Fisheries. 2021. "Achieving Local Energy Production and Consumption through Biomass Power Generation!" Accessed March 6, 2025.
https://www.maff.go.jp/j/pr/aff/2112/spe1_02.html

42 Blue Carbon Interagency Conference. 2023. "Collection of Blue Carbon Initiatives in Japan." Accessed March 6, 2025.
https://www.env.go.jp/earth/ondanka/blue-carbon-jp/pdf/materials/01_jp_1.pdf

43 Nagano Broadcasting. 2025. "High School Science Students Achieve Remarkable Feat: Their Research Wins First Place at an International Competition – Developing Small Balls Containing Green Algae to Absorb $CO_2$. Students: 'We Want to Share Its Impact with the World.'" Accessed March 12, 2025.
https://www.nbs-tv.co.jp/news/articles/?cid=21979

# Chapter 5 Conclusion

This proposal focuses on achieving an integrated transition toward energy systems that support Society 5.0, ensuring that energy transitions are closely linked with other policies and social transformations. The recommendations are categorized based on their implementation timeline: short-term (now until 2030) and medium- to long-term (2030–2050)

## Below are 14 key recommendations for realizing energy systems that support Society 5.0.

## [Short-term]

## Chapter 2: Japan in a new phase of green transformation

**1. Implement policies that turn the climate, energy, and environmental crises into opportunities for integrated transitions and work with diverse actors to promote the transformation of social systems.**

To link the current crisis concerning climate, energy, and environment to a green transformation in Japan, in conjunction with the Energy Master Plan, GX Policy, NDCs (Nationally Determined Contributions), and a comprehensive set of other policy priorities, an "integrated transition" must be achieved. It is necessary to recognize the interconnectedness of diverse actors in Japanese society, including government, local governments, businesses, universities, and civic organizations, and to aim to create policies that promote the transformation of social systems while avoiding "lock-in" to misaligned structures.

**2. Establishing transformative governance through funding, talent development, and scientific review**

For a long-term transition in climate, energy, and the environment, the government must support industries and local governments by focusing on funding, talent development, capacity building, and scientific review.

Policies must prioritize inclusiveness, fairness, and transparency in decision-making to prevent social inequalities. In addition, measures are needed to address rising energy costs and employment shifts affecting consumers by providing subsidies and structural transitions toward green jobs.

A transformative governance model that supports systemic social transformation should form the foundation of the long-term transition.

**3. Accelerating transition through energy optimization and innovation driven by the integration of AI, digital technologies, and existing energy systems**

The acceleration of the transition can be supported through AI and digital technologies, as well as by optimizing energy related to climate, energy, and the environment, and driving innovation in these fields. Japan must rapidly establish software and standards to ensure compatibility and interoperability, as well as energy data-sharing mechanisms. Furthermore, scientific analysis is essential to assess and mitigate the climate, energy, and environmental impact of AI and digital technologies, including data centers.

**4. Strengthening strategic partnerships in climate, energy, and the environment to demonstrate leadership in the Asia-Pacific region in a multipolar environment**

The current geopolitical landscape has created uncertainty in climate, energy, and environmental policies. In particular, the war in Ukraine has caused global economic disruptions, leading the EU to strengthen competitiveness policies while the U.S. is moving towards withdrawing from international climate efforts. Meanwhile, the Global South is gaining influence, significantly reshaping multilateral cooperation and supply chain networks. In this new phase of green transformation, Japan must leverage its existing relationships to enhance strategic partnerships to promote climate, energy and environmental transformation, while sharing interests in economic security and AI and other digital technologies. In particular, Japan is expected to establish its unique leadership in sustainable development within the Asia-Pacific region by sharing commitments, funding, talent, experience, and technology with Global South countries, which are playing an increasingly central role in these areas.

**Action by Hitachi-UTokyo Lab**

Through the analysis of international case studies, the latest academic research, and social surveys, we will explore the path to an integrated transition in Japan and the transformative governance needed to support it. Additionally, by engaging in dialogue with diverse actors, we will provide materials to facilitate inclusive consensus building. Furthermore, through collaboration between universities and businesses, we will work to develop talent equipped with specialized skills and advanced knowledge to drive the integrated transition forward.

# Chapter 3: The ideal path for the transition toward sustainable energy systems

**5. Review of energy scenarios in light of future cost burden**

With digital advancements, including generative AI, driving transformation across industries, electricity demand is expected to rise. According to the 7th Strategic Energy Plan formulated in February 2025, overall energy consumption in 2040 is projected to decrease by approximately 30% from current levels, while electricity consumption is expected to increase by around 20%. Hitachi-UTokyo Lab has examined multiple energy scenarios, taking into account the projected increase in electricity demand as well as the regional and temporal variability of renewable energy demand.. In addition to increased energy demand, the total cost, driven by energy infrastructure expansion and other factors, is expected to rise from 130% to 180% of current levels. This highlights the need for a stronger push toward a cost-conscious transition.

**6. Investment in innovation that bridges the backcasting and forecasting gaps in energy systems**

As the push for carbon neutrality continues, the gap between backcasting (goal-driven planning) and forecasting (current trend-based projections) is widening, requiring cost-conscious strategies to address this issue. If technological innovations are not implemented, additional costs of 4 to 10 trillion yen will be incurred across various energy scenarios by 2050. Therefore, the deployment of technological innovations must be carefully aligned with the expansion of renewable energy.

**7. Advancing the design of resilient medium- to long-term institutions and market frameworks alongside short-term market mechanisms**

With the liberalization of electricity markets, there has been an emphasis on economic efficiency based on short-term merit-order dispatch. However, it is necessary to reconsider this approach and establish a clear distinction between market efficiency and medium- to long-term policy goals such as resilience (stable supply) and decarbonization. Further refinement of market design is required to balance efficiency with these broader objectives.

**8. Restructuring the electricity market and integrating environmental value markets**

The current market framework is asymmetric, with uneven regulatory requirements across different players. This imbalance must be addressed urgently. To achieve this, transparency in power plant operations and stricter market monitoring are essential. Furthermore, integrating environmental value markets and encouraging innovative strategies from electricity retailers will help create a positive cycle toward carbon neutrality.

**9. Building a social system through regional and consumer participation**

A sustainable system that encourages proactive environmental investments by consumers must be established. This includes securing carbon-neutral energy sources through consumer-driven decisions, such as corporate power purchase agreements (PPAs), and integrating greenhouse gas reduction policies with consumer-centric emissions trading systems.

**Action by Hitachi-UTokyo Lab**

Hitachi-UTokyo Lab will engage in the development of energy scenario evaluation simulation technologies and assess CN transition scenarios in response to domestic and international developments. Additionally, it will focus on selecting and developing innovative technologies to address challenges within the energy system. Another key initiative is the proposal of a shared data and analysis model platform to facilitate collaboration among diverse stakeholders.

Furthermore, we will leverage digital technologies to enable data-driven $CO_2$ visualization and provide consumer-centric information on carbon neutrality. These efforts will contribute to the development of a consumer-led energy system.

# Chapter 4: Regional contributions to balancing CN and S+3E in energy supply and demand

**10. Regional contributions to balancing CN and S+3E in energy supply and demand**

Local communities are expected to play a central role in achieving S+3E through smart energy utilization, particularly by creating adjustment capacity. Key technologies to successfully transition these communities include digital solutions that enable visualization, control, and integration of consumer devices and energy usage. The rapid deployment of devices equipped with such digital technologies, along with the early social implementation of a coordination and control platform, should be prioritized.

**11. Implementing innovative strategies and policies to facilitate smooth regional transition**

For industrial decarbonization, businesses must proactively drive electrification and energy efficiency. Benefits for various stakeholders should be gradually realized to ensure this social transition.

Achieving CN in local communities requires continuity, safety, and economic viability from current lifestyles. Therefore, urgent actions should include providing mechanisms that support a phased transition, actively promoting trials that make effective use of existing equipment, and expanding time-of-use electricity pricing plans that secure tangible benefits for stakeholders.

**12. Objective analysis of social changes associated with CN and the formulation and trial implementation of growth strategies**

To steadily advance CN in local communities, it is essential to conduct objective analyses of energy usage across different sectors. In this version, we analyzed renewable energy utilization from a market perspective based on transaction data from JEPX and empirically quantified the social value that can be created through regional contributions under the existing framework. Key measures to accelerate an integrated transition while ensuring sustainable growth include revising market rules to fairly reward consumer contributions to energy coordination and establishing a database of equipment capable of providing adjustment capacity.

**13. Accelerating efforts toward nature-aligned negative emission technologies to expand and ensure transition pathways**

Negative emission technologies that leverage regional characteristics and coexist with natural restoration can expand transition options and their feasibility. Under a mid-term vision, developing human resources capable of driving both regional economic growth and carbon neutrality is crucial. This version presented case studies of blue carbon initiatives being promoted by multiple municipalities to simultaneously enhance $CO_2$ absorption and restore fishery environments, as well as examples of negative emission innovations led by younger generations. Education plays a critical role in regional communities as a foundation for daily life. Educational initiatives should: (1) address broad social issues to enhance environmental awareness, (2) foster basic knowledge and data literacy, (3) cultivate early-stage innovations into impactful solutions, and (4) inspire individuals to recognize how their actions can influence society.

**Action by Hitachi-UTokyo Lab**

Hitachi-UTokyo Lab will promote demonstration projects that contribute to S+3E-based energy supply and demand. Guided by a future-oriented vision, we will leverage information and knowledge to develop and disseminate actionable insights. We will expand collaborations with industry groups to discuss demand-side contribution strategies.

# [Medium to long term]

## Technical measures for energy systems (Chapters 3 and 4)

**14. Countermeasure technologies for energy scenarios towards achieving CN**

Towards 2040–2050, two key innovations will be necessary: (1) the practical implementation and widespread adoption of Direct Air Capture (DAC) for $CO_2$ removal, and (2) the development of technologies for producing fuel from captured $CO_2$ and its utilization in the transportation and industrial sectors.

In local communities, accelerating renewable energy adoption requires not only balancing supply and demand, but also preventing congestion in local grids and distribution substations. Mechanisms should be established to promote and utilize locally generated adjustment capacity, such as through local production for local consumption of renewable energy.

For innovations in carbon neutrality, in addition to technological advancements, efforts should focus on enhancing the CN literacy of leaders and citizens to sustain social transitions, as well as developing human resources who can lead integrated solutions to social challenges through interdisciplinary knowledge.

**Action by Hitachi-UTokyo Lab**

Beyond technology development, fostering leadership and advancing public education on carbon neutrality are crucial for continuous social transition. Hitachi-UTokyo Lab will continue providing evidence-based recommendations and creating opportunities for awareness-building through industry-academia-government collaboration. In addition to open forums and policy reports, we will create opportunities for multi-generational engagement, fostering talent development.

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WG1: Overall Energy Systems Working Group (Chapters 1 and 5)
WG2: Global Initiative Review Working Group (Chapters 1 and 5)
SWG1: Energy Systems and Frameworks/Policies Subcommittee (Chapters 3 and 5)
SWG2: Social Implementation Subcommittee (Chapters 4 and 5)
SWG3: Scenario Development Subcommittee (Chapters 2 and 5);
Underlined names are WG leaders

# Appendix 1

**Table A1.1 Key policies of European Union's Competitiveness Compass**

| Objective | Policy |
|---|---|
| Make business easier and faster | ● Introduce a new roadmap, the "Competitiveness Compass," with objectives of closing the innovation gap, decarbonizing, and increasing security.<br>● Complete the "Single Market" in key sectors to allow companies to scale up.<br>● Reduce administrative burden and reduce reporting obligations by at least 25% and at least 35% for SMEs. |
| Build new "Clean Industrial Deal" | ● Present a Clean Industrial Deal to make EU industry competitive and create quality jobs.<br>● Propose to set out 90% emission-reduction target for 2040 in the European Climate Law.<br>● Reduce energy costs for households and businesses by completing the Energy Union.<br>● Invest in clean energy infrastructure and technologies.<br>● Activate and extend EU's aggregate demand mechanism to go beyond gas and include hydrogen and critical raw materials.<br>● Secure supplies of raw materials, clean energy and clean tech with the development of clean trade and investment partnerships.<br>● Continue to be a leader in international climate negotiations.<br>● Encourage rail travel and propose Single Digital Booking for Europe. |
| Work towards a more circular and resilient economy | ● Help to create market demand for secondary materials and a single market for waste through a new Circular Economy Act.<br>● Put forward a new chemicals industry package, providing clarity on 'forever chemicals', or PFAS.<br>● Complete the European Health Union, diversifying supply chains, fostering access to most advanced treatments, making the health and pharmaceutical sector more resilient.<br>● Reduce dependencies on critical medicines and ingredients by putting forward a Critical Medicines Act.<br>● Step up work on preventive health, in particular for mental health, cardiovascular diseases, cancer, as well on treatments for degenerative illnesses and research on autism.<br>● Safeguard security of the EU healthcare systems by proposing a European action plan on the cybersecurity of hospitals and healthcare providers. |
| Boost productivity with digital tech diffusion | ● Encourage investments in digital infrastructures to improve access to secure, fast and reliable connectivity.<br>● Continue to step up our enforcement of the EU digital laws.<br>● Tackle challenges with e-commerce platforms.<br>● Step up investment in supercomputing, semiconductors, the Internet of Things, genomics, quantum computing, and space tech.<br>● Ensure access to supercomputing capacity for AI startups and industry via an AI Factories initiative.<br>● Boost new industrial uses of AI and improve public services with an Apply AI Strategy.<br>● Pool resources through new European AI Research Council.<br>● Ensure seamless and at-scale data sharing with a European Data Union Strategy. |
| Strengthen research and innovation | ● Increase research spending to focus more on strategic priorities.<br>● Expand the European Research Council and the European Innovation Council.<br>● Make it easier and faster to bring biotech from the laboratory to the market with a European Biotech Act.<br>● Support green and digital transitions and develop high-value technologies through a Strategy for European Life Sciences.<br>● Enhance collaboration between research departments, higher education and business by strengthening University Alliances. |

| Objective | Policy |
|---|---|
| Turbo charge investment | ● Put forward risk-absorbing measures to make it easier for commercial banks, investors and venture capital to finance fast-growing companies.<br>● Review EU rules to address barriers that restrict the amount of European capital available to finance innovation.<br>● Leverage private savings to invest in innovation and the clean and digital transitions with the establishment of a European Savings and Investments Union.<br>● Revise public procurement rules to enable preference to be given to European products for certain strategic sectors.<br>● Develop strategic technologies and manufacture them in Europe by establishing a European Competitiveness Fund that will also support Important Projects of Common Interest. |
| Tackle the skills and labour gaps | ● Establish a Union of Skills which will focus on investment, lifelong learning and skill retention.<br>● Work to improve basic skills.<br>● Propose a STEM Education Strategic Plan to address decline in performance, the lack of qualified teachers in areas linked to science, technology, engineering and maths (STEM) and bring more girls into STEM education and careers.<br>● Promote vocational education and training (VET) with a European Strategy for VET<br>● Boost and refocus skills funding in the EU budget.<br>● Ensure cross-country skill recognition by putting forward a Skills Portability Initiative and continue to work towards a European Degree. |

Source: European Commission. n.d. "A New Plan for Europe's Sustainable Prosperity and Competitiveness," https://commission.europa.eu/priorities-2024-2029/competitiveness_en, accessed March 5, 2025.

Table A1.2 Main elements of "Clean Industrial Deal"

| Element | Details |
|---|---|
| Affordable energy | ● Speed up the roll-out of clean energy, accelerating electrification.<br>● Complete the internal energy market with physical interconnections.<br>● Use energy more efficiently and cut dependence on imported fossil fuels. |
| Boosting demand for clean products | ● Through the Industrial Decarbonisation Accelerator Act, increase demand for EU-made clean products by introducing sustainability, resilience, and "made in Europe" criteria in public and private procurements. |
| Financing the clean transition | ● The Clean Industrial Deal will mobilize over €100 billion to support EU-made clean manufacturing.<br>● Adopt a new Clean Industrial Deal State Aid Framework to roll out renewable energy, decarbonise industry, and ensure sufficient manufacturing capacity of clean tech.<br>● Strengthen the "Innovation Fund" and propose an "Industrial Decarbonisation Bank," aiming for €100 billion in funding.<br>● Stimulate research and innovation in these areas by calling for participants under "Horizon Europe" research innovation program<br>● Amend the InvestEU Regulation to increase the amount of financial guarantees that InvestEU can provide to support investments. |
| Circularity and access to materials | ● Set up a mechanism enabling European companies to come together and aggregate their demand for critical raw materials.<br>● Create an EU Critical Raw Material Centre to jointly purchase raw materials on behalf of interested companies.<br>● Adopt a Circular Economy Act in 2026 to accelerate the circular transition and ensure that scarce materials are used and reused efficiently, reduce our global dependencies, and create high-quality jobs. |
| Acting on a global scale | ● Through the first Clean Trade and Investment Partnerships, diversify supply chains and forge mutually beneficial deals.<br>● Ensure the EU industry is economically secure and resilient, in the face of global competition and geopolitical uncertainties, through a range of trade defense and other instruments<br>● Simplify and strengthen the Carbon Border Adjustment Mechanism (CBAM), the EU's tool to put a fair price on the carbon emitted during the production of carbon intensive goods. |
| Skills and quality jobs | ● Establish a Union of Skills that invests in workers, develops skills, and creates quality jobs.<br>● Through Erasmus+, reinforce education and training programs to develop a skilled and adaptable workforce, and address skills shortages in key sectors, with up to €90 million in funding.<br>● Cut red tape, fully exploit the scale of the Single Market, promote quality jobs, and coordinate policies at the EU and national levels. |

Source: European Commission. 2025. "Clean Industrial Deal," https://commission.europa.eu/topics/eu-competitiveness/clean-industrial-deal_en, accessed March 3, 2025.

# 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.
  (primary energy, conversion sector, final consumption sector [industries, households, businesses, passengers, freight])
  Detailed analysis of energy sectors
  (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.

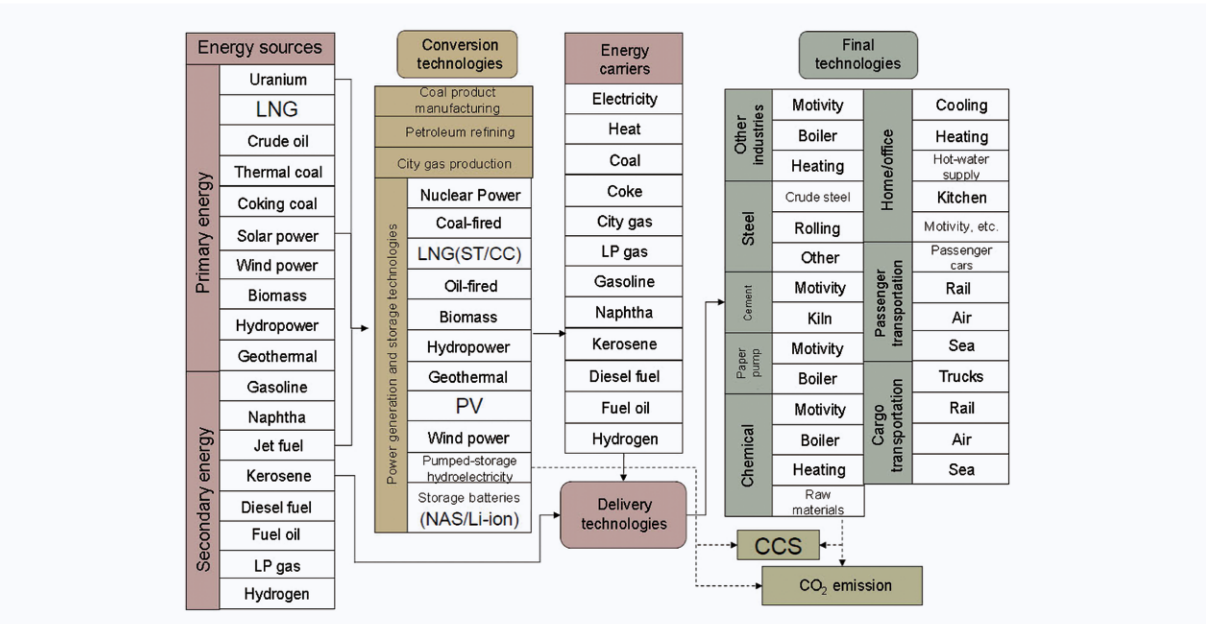



**Figure A2.1 Standard energy systems**

Figure A2.2 shows the main conditions (base conditions) of the simulation performed in Section 3.1. The conditions for each energy scenario are shown in Table A2.1. From Version 5, the upper limit on the introduction of renewable energy (offshore wind power) has been increased and updated in order to respond to the increase in electricity demand from data centers and other facilities.

- **Assumption: All major decarbonization tech (RE, nuclear, hydrogen, CO2 capture) are deployed**
- **Cost-optimized simulations for 2050 CN and transitions**

**CO2 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 CO2)

*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
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 scenarios

| | (1) 100% RE | (2) Thermal power with CCS limit | (3) Use of nuclear power | (4) Hydrogen procurement |
|---|---|---|---|---|
| Nuclear plant life (years) | Stopped | 60 | ← | ← |
| Nuclear plant cap. upper limit (GW) | 0 | 24 | 50 (SMR) | ← |
| Thermal power with CCS upper limit (ton) | 200 mil. | 100 mil. | 200 mil. | ← |
| Hydrogen import upper limit (ton) | 20 mil. | ← | ← | No upper limit |
| Hydrogen price (¥/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→200 | ← | ← | ← |
| Solar power construction cost (10k yen/kW) | 15 | ← | ← | ← |
| Onshore wind turbine construction cost (10k yen/kW) | 21 | ← | ← | ← |
| Offshore wind turbine construction cost (10k yen/kW) | 51 | ← | ← | ← |
| CCS cost (¥/ton$CO_2$) | 7450 | ← | ← | ← |
| DAC cost (¥/ton$CO_2$) | 10,340 | ← | ← | ← |
| LiB battery cost (¥/Wh) | 10 | ← | ← | ← |
| | RE only (e.g. PV and wind power) | Limited CCS for thermal power | Additional SMRs after 2040 | Import of hydrogen from overseas |

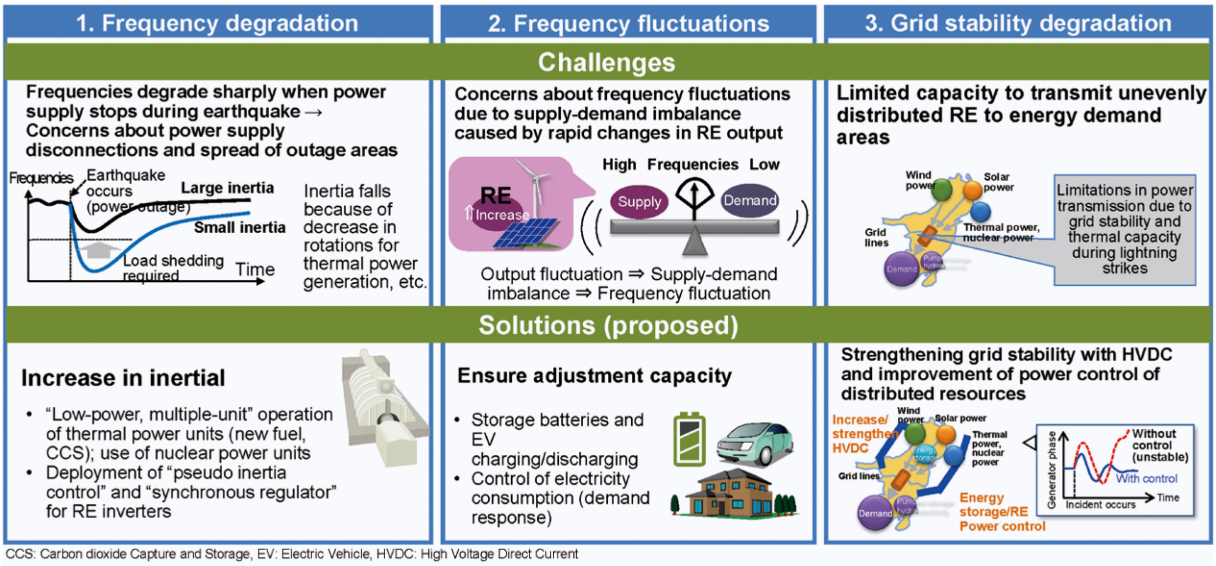
CN: Carbon Neutrality, CCS: Carbon dioxide Capture and Storage, DAC: Direct Air Capture, EV: Electric Vehicle, FCV: Fuel Cell Vehicle, SMR: Small Modular Reactor, LiB: Lithium-ion Battery



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

# Appendix 3 | Examples of issues and solutions of energy systems

Figure A3.1 shows issues and countermeasures in bulk power system accompanying a rapid expansion of renewable energy. Figure A3.2 shows issues and countermeasures of accompanying large-scale deployment of inverter power supplies in renewable-energy power supplies and storage systems.




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

**Figure A3.1 Issues and countermeasures in the bulk power system accompanying a rapid expansion of renewable energy**

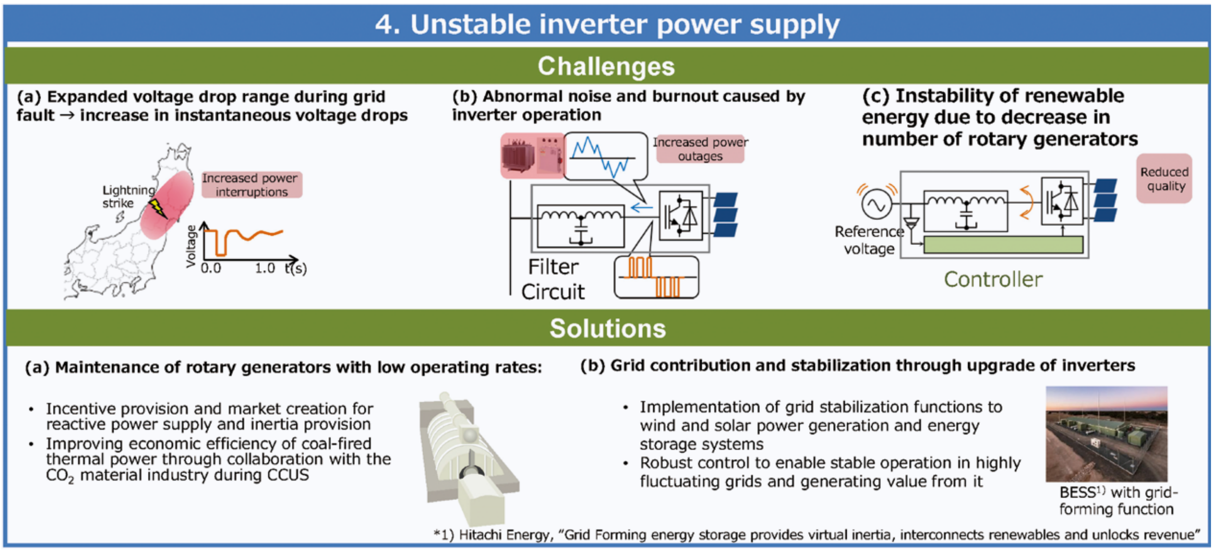



**Figure A3.2 Issues and countermeasure accompanying large-scale deployment of inverter power supplies**

# Appendix 4 | Demonstration of remote control of installed home heat pump water heaters to achieve adjustment capacity

Heat pump (HP) water heaters that satisfy demand response conditions are expected to be introduced to the market from 2029[1]. Considering that the average use of home HP water heaters is 12 years[2], it means that heat pump water heaters satisfying demand response requirements will become sufficiently widespread around 2040. Considering that the percentage of total energy generated by solar power will increase to 23 – 29% by 2040[3], HP water heaters already installed should be utilized promptly as adjustment capacity. Against this background, the Hitachi-UTokyo Laboratory has demonstrated remote control of installed home HP water heaters to achieve adjustment capacity. In this appendix, we give an overview of the demonstration environment and a portion of the demonstration results.

As shown in Figure A4.1, there are four methods for remotely controlling a HP water heater: (1) using a remote control switch, (2) using HEMS, (3) using the manufacturer's server, and (4) via a smartphone[4]. After comparing and evaluating these methods, we decided to use method (4), which allows the construction of a remote-control demonstration environment without additional equipment.

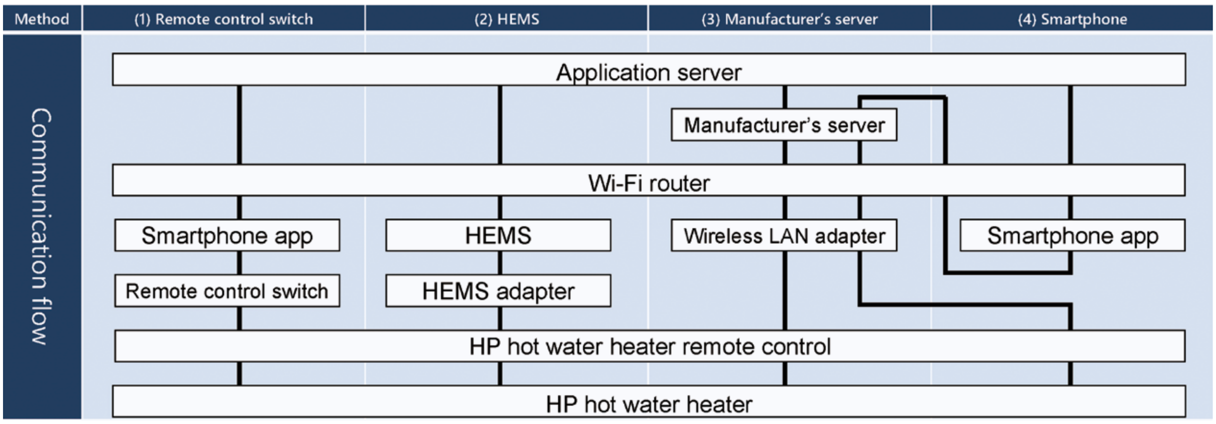
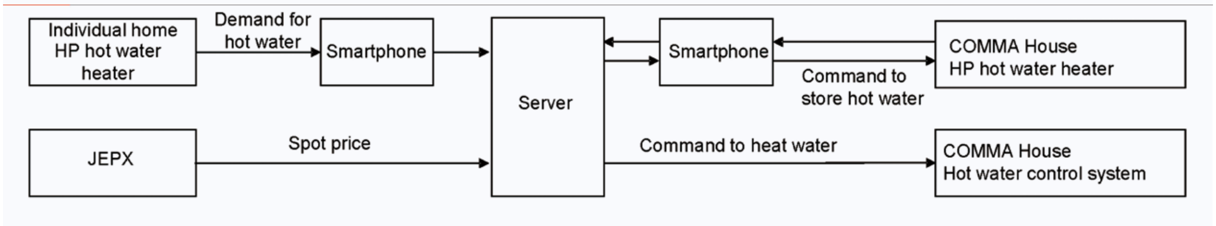



**Figure A4.1 Comparing remote control methods of heat pump water heaters**

When remotely controlling HP water heaters, it is essential to consider actual hot water demand and maintain the quality of home life. Specifically, it is necessary to ensure that hot water does not run out. Keeping in mind this point even for demonstration testing, we used the COMMA (COMfort MAnagement) House, an experimental smart house built on the University of Tokyo - Komaba Campus. Figure A4.2 provides an overall scheme of the demonstration system. A HP water heater (370 L) equivalent to the one installed in the homes of trial participants was also installed in COMMA House. Using a hot water delivery simulation system, we simulated hot water demand by participating homes with COMMA House. In this way, hot water demand is prepared. Individual homes operated hot water storage as usual from late night until early morning, while the Comma House operated hot water storage by remote control to enable economic operation tied to the spot market price of electricity in the Tokyo area. A series of the above actions were automated, making it possible to carry out long-term demonstration without inconveniencing the lives of participants in residential homes.




(a) Block diagram

(b) Installation of heat pump water heater (March 2024)


(c) Hot water control equipment


(d) Condition monitoring dashboard

**Figure A4.2 Remote control demonstration system**

We explain here remote-control issues faced during this demonstration. As shown in Figure A4.1, the communication flow is mediated by a smartphone, the manufacturer's server, and a Wi-Fi router. If any of the equipment fails, remote control becomes non-functional. During the demonstration period, there were cases of remote control failing due to circumstances such as updating of the smartphone and the manufacturer's server undergoing maintenance. Also, while the router did not fail during the demonstration period, it is necessary to prepare for cases of communication interruption due to equipment failure, and enable hot water storage by the HP water heater in a standalone manner.

Next, we explain the economic effect of shifting the hot water storage time in a HP water heater to a different time period. In this demonstration, the time required for water heating is set as four hours. We search for the time period with the lowest four-hour total of the next day's spot market prices, and issue a command for water heating during that four-hour period. Figure A4.3 shows the changing four-hour total of spot market prices from April 2024, when the demonstration began, to December 2024. It is the lowest four-hour total cost for each day. We call this the daily optimization case. For comparison, the late-night water heating case is shown. This is changing total cost of late-night hot water storage from 2 to 6 a.m. each day. From the graph, we see that during the months of intermediate electricity demand, where the spot market price is often 0.01 yen per kWh, the difference between the two cases is significant. On the other hand, during the summer, when the spot market price during late night/early morning hours become inexpensive on most days, the difference between the two cases become small.

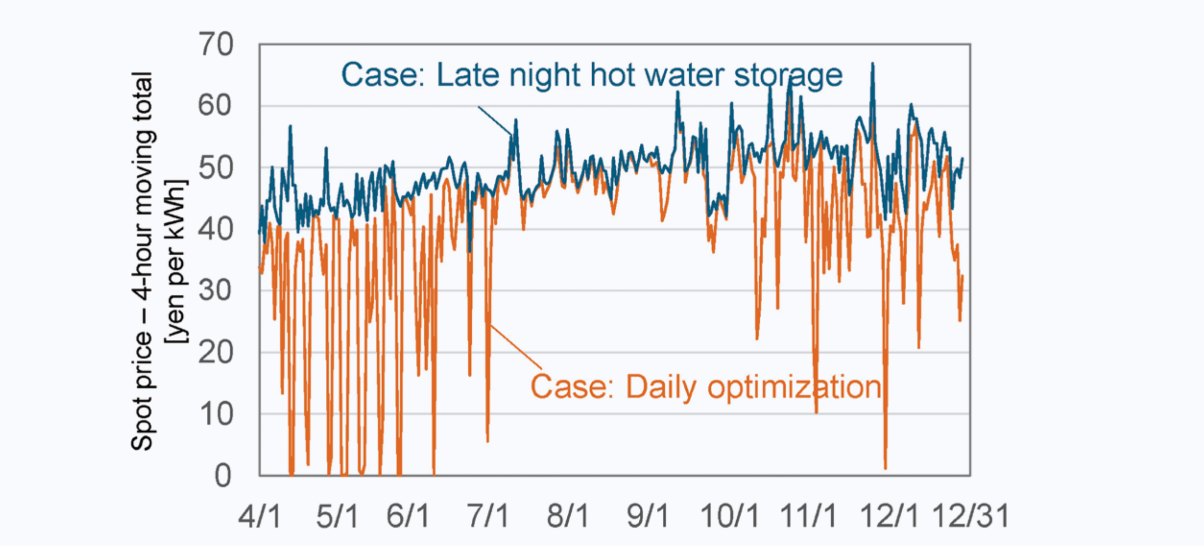



**Figure A4.3 Spot price (4-hour moving total) (yen per kWh) from April to December 2024**

The cumulative cost difference between the late-night water heating case and daily optimization case is the effect of reducing the cost of procuring electricity required for water heating in HP water heaters. Figure A4.3 shows the results of assuming four hours as the water heating duration. However, as revealed by this demonstration, the actual duration differs depend on the season. For example, the duration is 2.23 hours in July and 4.70 hours in November. Taking this fact into consideration, the reduction in electricity procurement cost from April to December 2024 is calculated to be about 3,000 yen. Assuming the cost to be about 4,000 yen per household per year and the stock of HP water heaters to be about 7.5 million units[5], a reduction cost effect of 30 billion yen per year nationwide is expected.

We will continue the demonstration, extract issues in the use of remote control, and evaluate its economic rationality.

1) Ministry of Economy, Trade and Industry. DRReady Study Group (January 28, 2025 materials). https://www.meti.go.jp/shingikai/energy_environment/dr_ready/pdf/004_03_00.pdf

2) Heat Pump & Thermal Storage Technology Center of Japan. "2024 electrification outlook survey." (September 2022 materials). https://www.hptcj.or.jp/Portals/0/data0/press_topics/R4TyousaHoukoku/R4DenkaFukyuMitoshi.pdf

3) Ministry of Economy, Trade and Industry. About the Energy Basic Plan (February 18, 2025). https://www.enecho.meti.go.jp/category/others/basic_plan/

4) Hatakeyama, et al. "Construction of demonstration environment for remote control of home heat pump water heaters for phased social implementation of regional energy coordination." 41st Energy System, Economy, Environment Conference (January 2025)

5) Ministry of Economy, Trade and Industry DRready Study Group (July 23, 2024 materials) https://www.meti.go.jp/shingikai/energy_environment/dr_ready/pdf/002_04_00.pdf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