東京大学
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HITACHI
Inspire the Next

Proposal

Toward Realizing Energy Systems to Support Society 5.0

(Ver. 3)

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Hitachi-UTokyo Laboratory

Executive Summary

From 2016, Hitachi-UTokyo Laboratory has been presenting visions and scenarios for energy systems that support Society 5.0. In Version 2 of the Proposal published in April 2019 (hereinafter, “Version 2”), an 80% reduction in CO_2 emissions compared to 2013, which is the CO_2 reduction target of the Paris Agreement, was set as the target under the policies aimed at the realization of a decarbonized society. With this as target, we presented a future vision of rebuilding local communities on the premise of the diversification of energy values as well as the coexistence between local communities aiming to build distinctive energy systems and the bulk power system that fulfills the role of connecting multiple local communities and coordinating the whole system. It is likewise important for stakeholders to be able to discuss on equal footing regarding various measures for future energy systems. Further, gaining social consensus on these measures entails the establishment of an evaluation platform for eliciting shared understanding through visualization on the premise of data sharing. The proposal discussed the necessary technologies, the conceptual design and materialization of the evaluation platform, and concrete measures for their realization, such as the relevant systems and policies and the development of human resources.

There is an increasing recognition of the manifestation of the impacts and damages brought about by global warming to human life and the natural environment in different areas around the world. In 2020, with the climate change problem becoming a common global issue, 120 countries and regions declared their commitment towards achieving carbon neutrality (CN). In Japan, Prime Minister Yoshihide Suga declared a pledge for the country to become carbon-neutral by 2050 in his general policy speech in October, and Japan’s Green Growth Strategy through Achieving Carbon Neutrality was announced on December 25, 2020. In response to these developments, Hitachi-UTokyo Laboratory discussed issues towards achieving carbon neutrality and initiatives to address those issues. We summarized the results of those discussions in this Version 3 of the Proposal.

We identified the following discussion points towards realizing carbon neutrality:

- How should social reform be pursued to achieve carbon neutrality? Transition strategies must be formulated based on Japan’s current state.
- What are the technologies and systems needed to balance reform and value creation in local communities to realize a carbon-neutral society?

- What is the optimal balance in the carbon-neutral society for the [3E+S][1] tetralemma of bulk power systems, and what are the technologies and systems to realize that balance?
- There is a need to make investments to drive the above changes. What systems and policies should be devised to promote those investments?
- How should human resources be developed to enable them to have a multifaceted and comprehensive understanding of social issues in a carbon-neutral society and to identify and solve the fundamental issues?

To address these issues, we propose the following in Version 3 of the Proposal.

(1) **Construction of diverse energy distribution systems to realize carbon neutrality premised on the participation of all stakeholders**

Achieving carbon neutrality in 2050 entails large-scale reforms in all aspects of energy—production, distribution, use, and circulation—beyond electricity systems. This requires promoting reforms participated in by all members of society to achieve advanced integration of services, including information, transportation, and logistics.

(2) **Construction of systems for utilization of energy data to create new value in local communities and bulk power systems as well as support carbon neutrality**

Social changes should be envisaged based on signs for the future as well as the current situation to create and offer new values through energy and promote the sharing of data, which are the sources of those new values.

(3) **Formulation of societal-level measures that take the allocation of power demands, including VPP[2]/DR[3], hydrogen production, etc., into account in order to enable the mass deployment of renewable energy, which will take center stage in a carbon-neutral society**

Realizing carbon neutrality entails the deployment of more than 300 GW of variable renewable energy (hereinafter, “renewable energy”) as an energy source capable of meeting the increase in demand following the electrification of non-electrified equipment. Also, the shift to carbon neutrality in the industrial sector and in long-distance mobility is expected to lead to the utilization of hydrogen and other new green fuels, and the use of renewable energy in the production of these green fuels. Systematic locations of production centers will enable the localization of renewable energy and ensuring adjusting capacity in response to output fluctuations. In other

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[1] Based on the first letters of Economy (E), Environment (E), Energy (E), and Safety (S).
[2] VPP: Virtual Power Plant
[3] DR: Demand Response; Consumers change their power consumption patterns by controlling their use of power depending on the setting of electricity prices and paying of incentives when there is a rise in market price or when the grid becomes unreliable.

words, it will be possible to minimize investments into the power grid following the mass deployment of renewable energy.

(4) **Construction of international frameworks for discussions aimed at evidence-oriented policy planning and standardization towards achieving carbon neutrality**

To clarify the developments needed for shifting to carbon neutrality and the investment areas for those developments, the ideal form and the strategies for reform to achieve the ideal form must be actualized. Long-term strategies must be formulated based on scientific evidence along with the building of frameworks for circulation of funds needed to promote innovations. Also, to protect national interests, it is essential to make active contributions in international coordination and rule-making, such as in discussions related to carbon pricing.

(5) **Creation and sharing of "transition scenarios" that lay down the path to comprehensive structural reforms that need to be carried out in different sectors, towards the steady realization of a carbon-neutral society**

Realizing carbon neutrality requires accurate presentation of how energy sources and power grids should be implemented, as well as of the ways to achieve multifaceted structural transformation, including cities, lifestyles, industrial structures, and decision-making approaches. We will present transition scenarios towards realizing carbon neutrality based on the ideal form of society and of the private and public sectors, by 2030 and 2050.

(6) **Development of cross-functional human resources through industry-academia-government collaborations**

To build an energy system that supports Society 5.0 along with creating an infrastructure industry that contributes to the global society, scientific and technological innovation, social systems, and economic mechanisms must be assessed as an integrated whole. Industry, academia, and the government must work together to promote efforts beyond industrial, academic, and generational boundaries, and create opportunities to develop human resources capable of consolidating discussions on multifaceted values.

Toward Realizing Energy Systems to Support Society 5.0

Introduction

In recent years, factors such as the mass deployment of renewable energy sources, expansion of information technology, advancements in globalization, and changes in people's values have greatly altered the processes by which knowledge and value are created, thus ushering in an era of transformation with respect to the state of the economy, society, and industrial structure. Currently, the Japanese government has enacted policies that aim to create new values in response to such economic and social changes, permeate the vision of a super-smart "Society 5.0" of the future to enable prosperous livelihoods, and be a torchbearer in solving social issues.

The realization of Society 5.0 has become increasingly important in the light of the accelerating transformation of society, as shown by the heightened resilience awareness due to worsening natural disasters, the diversification of people’s lifestyles due to the worldwide COVID-19 pandemic, the rapid progress of digital transformation (DX) of corporate activities, and the declaration of commitment to carbon neutrality by 2050 by countries around the world including Japan. In particular, the CN declaration has triggered a major change in mindset in the industrial sector, i.e., that economic development is not possible without first addressing the climate change problem.

At the University of Tokyo (hereinafter, “UTokyo”), researchers believe that, in order to solve society’s complex global issues, one must look beyond the confines of a single scientific field, consolidate diverse findings from a global perspective, and co-create knowledge. UTokyo researchers have combined research results across various fields involved in these global-scale issues and have contributed to policy formation. In addition, UTokyo has likewise developed an academic base for the cultural integration of the East and the West. In the future, they intend to carry on such traditions while envisioning themselves as the Global Base for Collaborative Knowledge Creation, attracting people from around the world, and transforming the search for knowledge into the utilization of knowledge. The Center for Global Commons was established in August 2020 based on this vision and as part of this global base. UTokyo is currently promoting the idea of collaborative creation (co-creation) between industry and academia, whereby industries and academic institutions can share directionality and actively draw on synergistic effects to tackle large-scale issues and fortify functions that help create new social value.

On the other hand, Hitachi Ltd. (hereinafter, “Hitachi”) has been promoting a social innovation business that combines infrastructure technology (that they have developed over the years) with advanced IT. They seek to create new values using digital technology in order to accelerate co-creation between customers and partners, thus promoting open innovation and providing optimal solutions for social issues.

On June 20, 2016, UTokyo and Hitachi jointly established the Hitachi-UTokyo Lab on the UTokyo campus under the strategy "Collaborative Creation between Industry and Academia." The laboratory was set up to integrate the efforts of these two institutions, create a vision to achieve "Society 5.0" to bring prosperity to humanity, and yield innovation.

As one of its areas of activity, the laboratory has examined an energy system (particularly the electricity system) needed to underlie the data-driven Society 5.0. In particular, since achieving carbon neutrality requires structural transformation of the entire society, it is critical to build consensus on multiple alternatives among various stakeholders. Therefore, in this Version 3 of the Proposal, we will identify technical and policy/institutional issues pertaining to the future of the energy system that will sustain Society 5.0, pursue discussions on transition strategies for social reform including consensus-building with stakeholders, and share these findings with relevant parties and publish them as recommendations.

Direction of Discussions

Aiming for a transition to society that generates new value along with the shift to carbon neutrality, we discussed the strategies for that transition, the frameworks for decision making, the planning of systems and policies that will trigger the changes, and the issues pertaining to the development of human resources who will carry these responsibilities out. Discussions were carried out along four major axes with respect to the electricity systems that will support Society 5.0 on the premise of carbon neutrality.

A) Propose a vision for Energy Systems to Support Society 5.0

Recognizing that the energy system is an important infrastructure that significantly affects the individual consumer lifestyle beyond its conventional role of simply providing energy, we will strive for the establishment of Society 5.0, which will create new industries and jobs. We will pursue this goal while taking advantage of Japan’s high reliability, technical capability, and human capital, and while contributing to the international community by disseminating the established vision and relevant information and by providing technical capability.

The Ministry of Economy, Trade and Industry’s (METI) Green Growth Strategy through Achieving Carbon Neutrality announced on December 25, 2020 presented national directions towards achieving carbon neutrality by 2050. The strategy presented policies on diverse alternative sources of energy, including hydrogen and ammonia power generation, nuclear power, thermal power with CCUS, and carbon recycling, in addition to previous policies to promote electrification and the shift to renewable energy as main energy source. Technologies for energy infrastructures must be developed while gradually setting appropriate milestones in consideration of the lead time to their construction. To strategically implement the various policies, we must formulate mid-to-long-term visions towards 2030 and 2050 and discuss the systems and policies to realize those visions. Strategic national investments will be needed given the high level of uncertainty in the development of technologies in the mid-to-long-term scenarios and considering that these will not be ruled by market principles alone.

B) Transition strategies for social reform

Realizing carbon neutrality requires multifaceted discussions on electricity systems, as well as discussions on cities, lifestyles, industrial sectors, and human decision-making processes. Also, social structural reforms entail a positive cycle of investment, benefit, and re-investment through gradual reform of systems that benefit the stakeholders. Transition strategies must be formulated based on existing research results on global scenarios and transition scenarios as well as on the frank opinions of stakeholders. Strategy formulation necessitates clearly identifying the issues and challenges in creating future scenarios going forward.

C) An open framework for social decision making

To achieve social consensus on energy systems, we must anticipate future economic and social changes and establish frameworks for discussing various directions from a wide perspective, knowing that it is not enough to simply deal with the issues at hand. As is obvious, ensuring economic performance is also important in a carbon-neutral society; therefore, the ideal form of the future energy system should be discussed and shared across the entire society. For this purpose, it will be necessary to provide a platform for open, quantitative/objective information dissemination/sharing, along with a framework for decision making that takes this information into account. Every effort should be made to share transparent and reliable data and tools pertaining to energy systems in order to promote information-sharing among stakeholders, through cooperation among industry, academia, and the government. Such open debate will likewise encourage healthy competition among energy systems. Information and data are valuable assets for continuously creating values for the society, community, and individuals. Mechanisms must also be established to ensure that data are shared while maintaining their safety and reliability.

D) Development of cross-functional human resources

To build an energy system that supports Society 5.0 and create an infrastructure industry that contributes socially on a global scale, it is imperative to assess scientific and technological innovation, social systems, and economic mechanisms as an integrated whole. Industry, academia, and the government must work together to promote efforts beyond industrial, academic, and generational boundaries, and develop human resources capable of discussing multifaceted values and integrating diverse knowledge.

Vision Formulation for Society 5.0	• Promote discussion of systems and policies and provide multiple technology options for realizing a carbon neutral society with the participation of all stakeholders. • Leverage Japan's strong credibility, technology, and human capital. • Continuously invest in technological development for medium/long-term scenarios from a national perspective. • Contribute to the international community by disseminating established vision and technical information.
Transition strategy for social reform	• Carry out multifaceted discussions on energy transition, including approaches for electricity, cities, lifestyles, industrial structures, and decision-making processes, and create and implement systems that promote a positive cycle of investment, benefit, and re-investment. • Clarify issues and challenges in formulating scenarios by incorporating the frank opinions of stakeholders while considering existing research on scenarios.
An open social decision-making framework	• Create a platform for open, quantitative/objective information sharing and a framework for decision making with the goal of sharing the ideal form of energy systems to ensure decarbonization and economic sustainability. • Share data and analytical tools as much as possible to achieve social consensus.
Training cross-functional human resources	• Assess scientific and technological innovation, social systems, and economic mechanisms as a whole to create new infrastructure industries. • Create opportunities to develop and assess human resources capable of discussing multifaceted values and integrating diverse knowledge.

Figure i: Direction of discussions

Main points of the previous proposals (Outline is shown in Figure ii)

- Rebuilding of energy systems on the premise of the coexistence of local communities and bulk power systems.

  Figure iii shows the overview of the energy systems that support Society 5.0 as proposed by Hitachi-UTokyo Laboratory.

  In Society 5.0, individual lifestyles will take center stage and energy systems distinct to each local community will be built. Data will play an important role in this new society, providing not only electricity but also new values and services. The bulk power system will optimize the "3E + S" of the entire society. The roles of the local community and the bulk power system will no longer be uniform; they will be redefined on the assumption of coexistence. There will be an exponential increase in factors that must be coordinated and adjusted, such as the decentralization of power sources, coordination between the bulk power system and multiple local communities, and human behavior. It will be necessary to establish a new mechanism to facilitate coordination that can integrate these distributed resources.
- Flexible decision making from a medium-to-long-term perspective to reform the structure of the whole society

  Amid mounting mid-to-long-term uncertainties caused by global economic and social changes and technological innovations, it is important to infer and formulate multiple long-term energy scenarios to realize Society 5.0. Technology development and facility deployment to the energy infrastructure must be considered in spans of 5-10 years (short-term), 10-20 years (medium-term), and 20-100 years (long-term), to clarify development items and investment areas by visualizing the future of the energy system.
- Participation of various stakeholders to create new values for the energy systems supporting local communities

  Local communities must gear towards a new direction: technological innovation and system upgrades to create, distribute, and trade unique values amid the diversification of energy values. For example, communities located in areas well-suited for renewable energy should strive to utilize that surplus power to foster local industries, in addition to developing various stabilization measures for the electricity system. They should create new service businesses by establishing a mechanism to publicly share information among various infrastructural services, including electricity, gas, water, IT, transportation, and logistic services.
- Bulk power systems serving to connect local communities within the important role of optimizing 3E+S

  As energy systems change, bulk power systems will assume the important role for the total optimization of 3E+S for society as a whole. In addition, bulk power systems will connect multiple local communities as they exchange energy supply, demand, and values. To discuss the ideal form of the bulk power system, a platform will be built to evaluate the energy systems of the entire society. Analytical tools and standard data will be developed and shared through industry, academia, and government collaborations. On the basis of the evaluation results, various stakeholders will discuss and form a social consensus on the role of the bulk power system and invest in its transformation. In addition, they will incorporate and implement new control technologies that will digitally connect the bulk power system to the local community, and globally roll out the technologies and experience.

- Conceptual design of the evaluation platform and data sharing

  Evaluation platform users will be defined, use cases will be inferred and abstracted, and required specifications and functions will be identified. The evaluation platform for energy systems assumes information and data sharing of the power system, power generation, and demand, with each possessing constraints, such as information security for key infrastructure, protection of information related to the competitiveness of power plants, and personal privacy protection. It will be necessary, therefore, to disclose and publicly release information in an appropriate capacity; the scope of disclosure should be determined on the basis of required specifications and functions described above. In addition, the evaluation platform needs continuous improvements and updates, requiring an appropriate operator to be specified.

- Development of systems and policies rooted in diversity to promote the transformation of local communities and bulk power systems

  An important challenge is to set up systems and policies for energy systems to embrace new endeavors and reforms. The future vision of energy systems must be fleshed out to identify what developments and investment areas are needed, and thereafter implement them as long-term plans. We will review systems and policies to promote the restructuring of bulk power systems and local communities. For the former, we will propose simultaneously accelerating investment and efficiency through performance-driven policies. For the latter, a system must be built to optimize 3E+S for the entire society based on the interconnection of multiple local communities while implementing strategies that meet the characteristics of each local community. In addition, a mechanism must be built to circulate funds and promote innovation to facilitate the conversion of the energy system. Using the various evaluation platforms described above, we will develop a long-term energy strategy based on scientific evidence and create a positive cycle of investment and the revitalization of regional economies.

- Development of cross-functional human resources with the collaboration of industry, academia, and government

  To build an energy system that supports Society 5.0 and create an infrastructure industry that contributes to the global community, it is important to assess scientific and technological innovation, social systems, and economic mechanisms as an integrated whole. Industry, academia, and government must work together to promote efforts beyond industrial, academic, and generational boundaries, and foster human capital capable of discussing multifaceted values. It will also be important to utilize seasoned professionals, who are valuable assets in Japan.

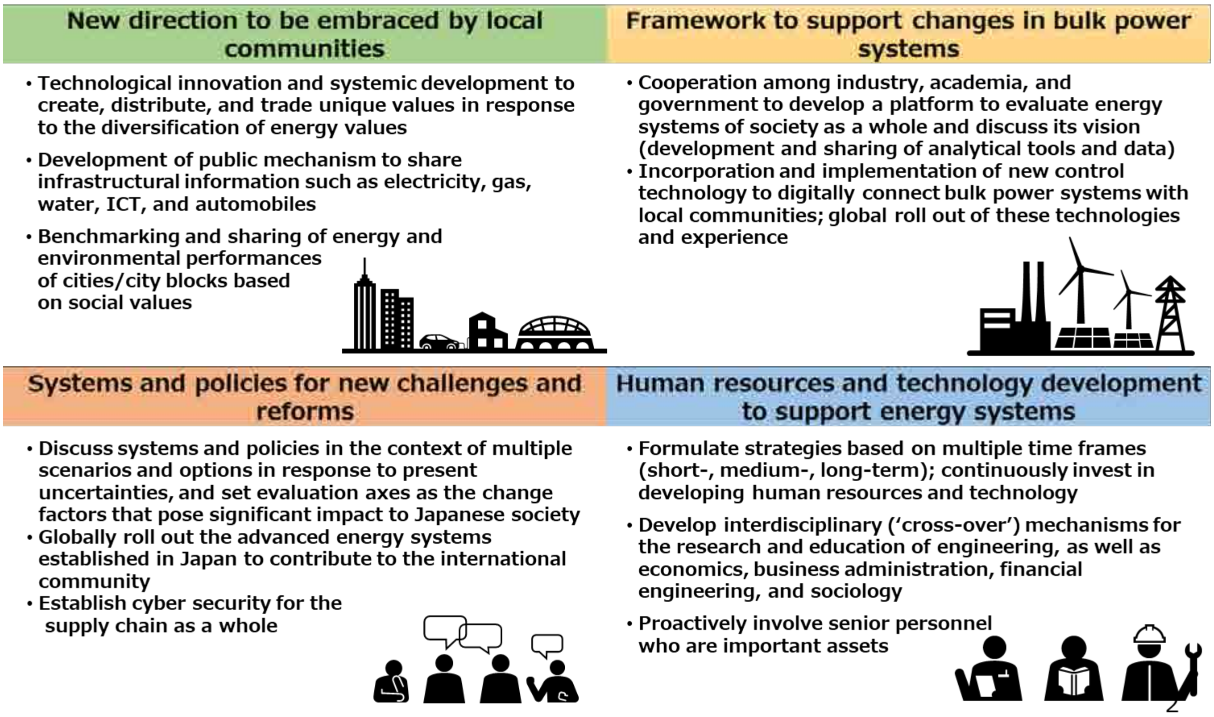

Figure ii: Discussion points in previous proposals

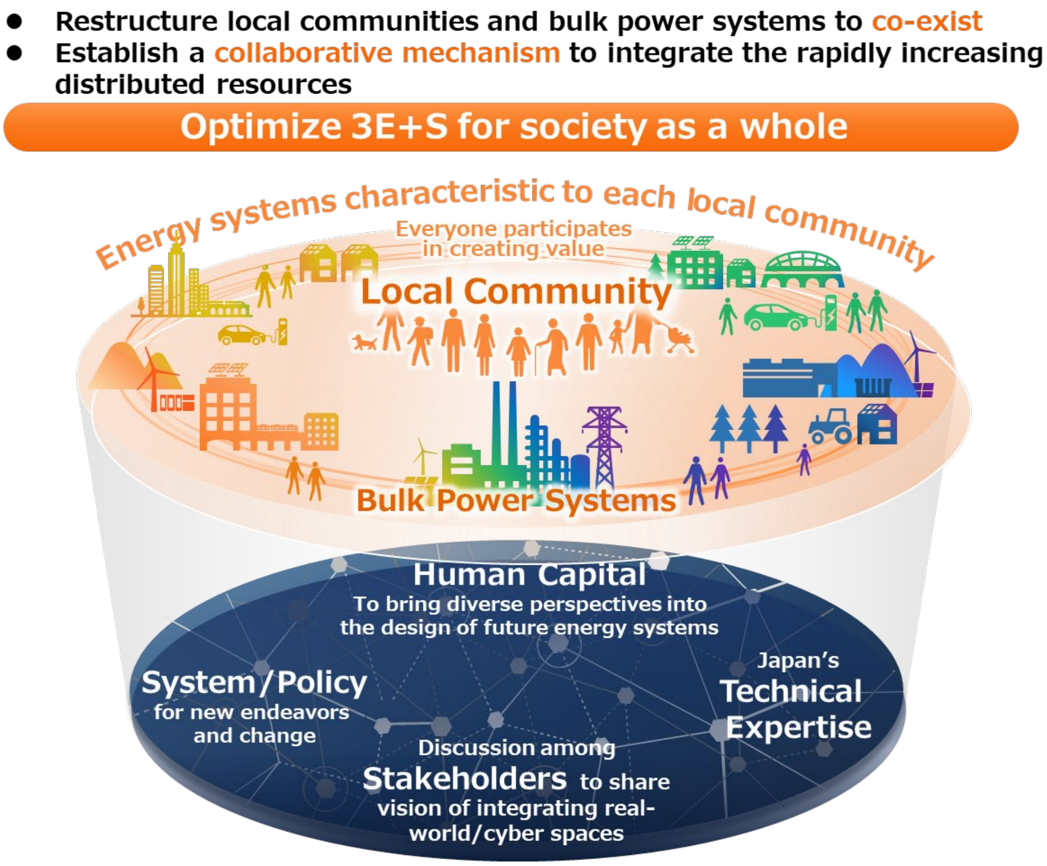

Figure iii. Overview of energy systems to support Society 5.0

Revised Aim and the Main Points of Ver. 3

A major social change has occurred after Version 2 of the Proposal was published in April 2019, namely, countries around the world declared their commitment to carbon neutrality in response to the manifestation of climate change problems. Japan has likewise presented at the end of 2020 a government policy towards achieving carbon neutrality under the Green Growth Strategy framework. Hitachi-UTokyo Laboratory has been advocating for the quantification of long-term energy scenarios to reduce CO_2 emissions by 80% (to 238 Mt-CO_2) in 2050 compared to 2013, based on the CO_2 reduction target of the Paris Agreement. In response to Japan's declaration of its commitment to CN, we set out to clarify the technical challenges and present measures to achieve carbon neutrality, as well as formulate transition strategies that involve large-scale structural changes in society, in reference to the policy directions given by the government.

Achieving carbon neutrality entails discussions across society as a whole, including the non-electrified sectors that rely on fossil energy, aside from the sectors relying on electricity systems. Further, the society in 2050 is expected to be different from today in various respects, such as people's values and lifestyles, pointing to the need for comprehensive discussions that also take social reforms into consideration. We will envision the ideal form for 2050 and formulate transition strategies based on backcasting from that ideal form. The following are the major points of Version 3.

(1) The ideal form of future energy systems (Mainly Chapter 1)

Ever since the European Council made its declaration towards carbon neutrality in February 2020, more than 120 countries and regions have now declared their own commitment to CN. While recognizing the unique issues that Japan faces towards achieving carbon neutrality, we will aim for the prompt realization of Society 5.0, which will be the key to Japan's achieving global leadership.

(2) Hitachi-UTokyo Laboratory's Technology Conversion Scenario and policies towards achieving carbon neutrality (Mainly Chapter 2)

In Version 2, we used two evaluation axes; namely, decarbonization (achieving 80% domestic reduction in CO_2 emissions, and global reduction in carbon footprint using CO_2 credits) and decentralization (concentration of population near metropolises like Tokyo and Osaka, and distribution of medium-sized hubs through regional revival and revitalization) to study the long-term energy scenario. We quantitatively evaluated the four scenarios that form the two axes and discussed the technical and policy/institutional issues. Reduction in CO_2 emissions by 80% is more or less possible by promoting decarbonization of energy sources and electrification/motorization. Achieving carbon neutrality, however, requires structural changes in society as a whole, including long-distance mobility and industrial sectors untenable to electrification, as well as changes in people's awareness. These are issues that cannot be addressed simply by extension of previous discussions. It is therefore imperative to recognize that there has been a major change in premises, thus, we will discuss the necessity of reforms.

(3) Diverse coordination mechanisms between bulk power systems and local communities (Mainly Chapter 3)

In the previous Proposals, we explained the desirability of building energy systems distinct to each local community, where individual lifestyles take center stage. To realize this, we discussed the importance of collaboration and cooperation among social infrastructures, including electricity, gas, water, ICT, transportation, and logistics, to distribute new energy values.

In a carbon-neutral society, 3E + S will be realized through the participation of an even higher number of energy consumers and providers in the energy coordination mechanism. Local communities will see the full-scale deployment of electric vehicles (EV) with the support from a government policy pushing for 100% share of electric motor cars[4] in new vehicle sales by the middle of 2030. Hence, there is a need to build the systems and frameworks for EV and the non-electrified sectors to participate in the coordination mechanism before 2030 when their full-scale deployment begins. Meanwhile, combustion-based and other industries untenable to electrification will require alternatives for provision of new fuels, such as hydrogen and ammonia, as substitute for conventional fossil fuel and for a circulation system to recycle the emitted CO_2, in consideration of the large volume of energy they need. Hydrogen and new fuels require the building of new distribution infrastructures, pointing to the need for establishing an evaluation platform for planning and supporting infrastructure building based on coordination with the existing energy networks, i.e., the electricity systems. At the same time, since dependence on electricity will increase with the advancement of electrification, it is also important to ensure resilience against the increasingly severe and frequent natural disasters.

(4) Bulk power systems responsible for comprehensive energy provision (Mainly Chapter 4)

In the previous Proposals, we presented the necessity of platforms to quantify future issues and evaluate the return on investments for bulk power systems as they are positioned to play a role in optimizing the 3E+S of the entire society. The energy needed for producing hydrogen and new fuels in a carbon-neutral society must be supplied

[4] General term for vehicles using electricity as power source; includes electrically powered vehicles and fuel-cell vehicles.

through renewable energy and other carbon-free energy sources (green hydrogen and green fuels). Also, following the progress in ICT, 5G, and other communication technologies, power consumption in data centers is expected to rise sharply. The government’s Green Growth Strategy foresees a 1.3 to 1.5 increase from the current power demand by 2050, which is similar to the forecast in Version 2 of the Proposal. The increase in power demand and the regionally uneven expansion of the renewable energy ratio should not only be dealt with by simply reinforcing the bulk power systems. Instead, existing infrastructures, including nuclear power plants, should be fully utilized, and an overall design that includes demand plans must be made at the societal level for manufacturing sites for hydrogen and new fuels, and other energy sources.

(5) Formulation of systems and policies to address new challenges and reforms (Mainly Chapters 3 and 5)

In the previous Proposals, we studied systems and policies to promote the restructuring of bulk power systems and local communities. For the former, we proposed simultaneously accelerating investment and efficiency through performance-driven policies. For the latter, we proposed a framework for optimizing 3E+S for the entire society and interconnection of multiple local communities. Regional planning and implementation should be promoted through incentives such as tax breaks and assistance, while striving for optimal balance between top-down decision making and bottom-up planning and execution. Stakeholders should be encouraged to invest in energy systems, which will promote a circular economy and support regional revitalization.

When a cold wave hit Japan in January 2021, the JPEX price skyrocketed due to the tight supply-and-demand balance. Total optimization of 3E+S, which is premised on stable supply, should be reconsidered, and the limits of market mechanisms should be discussed. Also, to protect national interests, it is essential to make active contributions in international coordination and rule-making, such as in discussions related to carbon pricing. “Visualization” of various domestic institutions, particularly Japan’s national systems, should be pursued. Further, to increase awareness regarding carbon neutrality, it is also important to have mechanisms for consumers to “visualize” the CO_2 emissions of products and services.

(6) Formulation of new energy scenarios (Mainly Chapter 6)

Achieving carbon neutrality entails the implementation of different relevant measures, as well as a comprehensive view of the entire society. We will envision the “ideal form” of energy systems for 2050 and create backcasting scenarios based on multiple pathways leading to the realization of that ideal form. We will create scenarios premised on the realization of carbon neutrality by taking a comprehensive view into 2050 from the social, public, and private perspectives. In this Version, we discuss the overview of the scenarios and their formulation process.

Contents

Chapter 1: The Ideal Form of Future Energy Systems

We will clarify Japan's situation while consolidating the global trends surrounding the environment and energy. From this, we will present an overview of energy systems to support Society 5.0 and identify the challenges to their realization.

1.1 Global Trends in Environmental and Energy Problems

The climate change problem is a pressing and urgent problem. In 2015, the international community adopted the Paris Agreement at COP21 and ratified it in 2016 as an international framework for reducing greenhouse gas emission from 2020 onwards. This international agreement is a concrete embodiment of SDG 13: "Take urgent action to combat climate change and its impacts." It aims to keep the increase in global average well below 2 ℃ above pre-industrial levels, and to pursue efforts to limit the temperature increase to 1.5 °C.

However, there is a significant difference between an increase of 2 ℃ and an increase of 1.5 °C in terms of the risks of melting of the Arctic ice. This prompted the European Council to adopt a proposal for a European Climate Law in March 2020, legislating government commitments to achieve net zero greenhouse gas emissions by 2050 on the premise of a 1.5 °C temperature increase limit. The adoption of this proposal led to the carbon neutrality declaration by now more than 120 countries and regions around the world. The following are the initiatives towards achieving carbon neutrality by the major countries and regions.

Europe

[EU]

The European Union aims to achieve carbon neutrality across the entire EU through the use of a diverse energy mix by promoting renewable energy focusing on offshore wind power and establishing an internationally interconnected power distribution grid. The European Council has submitted the Nationally Determined Contributions (NDC) based on the Paris Agreement of the EU member states to the United Nations Framework Convention on Climate Change (UNFCCC). The submission includes a target of at least a 55% reduction in greenhouse gas emissions by 2030 compared to 1990[5]. The European Council has also announced a green recovery plan as part of an economic stimulus measure to avoid delays in decarbonization initiatives caused by the COVID-19 pandemic[6].

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[5] Europe Magazine. 2020. EU transmits NDC submission for Paris Agreement aiming for at least a 55% reduction in greenhouse gas emissions by 2030 compared to 1990 (https://eumag.jp/news/h121820/)

[6] An official website of the European Union. Recovery plan for Europe (https://ec.europa.eu/info/strategy/recovery-plan-europe_en).

[U.K.]

In June 2016, the UK passed a bill to amend its climate change law by setting a new target requiring the UK to bring all greenhouse gas emissions to net zero by 2050[7]. In November 2020, it announced the Ten Point Plan that aims to achieve a balance between the economy and the environment. The Plan includes targets on development of green energy (offshore wind, hydrogen, nuclear power), bolstering of electric vehicles, decarbonization of road, air, and sea transport, greening of homes, capture and storage of CO_2, planting of trees, innovation of technologies, investments, etc. The government will mobilize 12 billion pounds (approximately 1.6 trillion yen) to generate and support employment of 250,000 people[8].

[U.S.]

Although there has been delays in national initiatives towards carbon neutrality prior to the Biden administration, Governors of some states like California and Hawaii have independently issued orders towards achieving carbon neutrality for their states by 2045 (September 2018). The country has also launched the H2@Scale Project to explore the potential for wide-scale hydrogen production and utilization in the US to enhance international competitiveness and job creation (2016 onwards), among other early initiatives. The Biden administration has likewise made a public commitment to shift to carbon-neutral power by 2035, while at the same time generating one million jobs in the EV business to accommodate the loss of jobs in the fossil fuel industry.

[China]

China aims to achieve carbon neutrality by 2060. Aside from being the world's largest emitter of CO_2 (28.2% in 2017), it also has to tackle the issue of high dependency on coal. The western part of China receives more than 2,500 hours of sunlight annually with prevailing westerlies blowing over large areas of the region. The renewable energy resources of this region will likely be leveraged to achieve the country's decarbonization goals. China accounts for almost half of global EV sales and has been accelerating EV deployment by establishing systems for prohibiting entry of gasoline-powered vehicles into cities and giving preferential treatment for license plate acquisition for new energy vehicles. Also, in anticipation of automatically driven EV, China has started trials in 2018 to collect real-time data on vehicle location and battery usage.

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7 GOV.UK. News story – UK becomes first major economy to pass net zero emissions law (https://www.gov.uk/government/news/uk-becomes-first-major-economy-to-pass-net-zero-emissions-law)

8 GOV.UK. 2020. UK government's Ten Point Plan on climate change countermeasures (https://www.gov.uk/government/news/pm-outlines-his-ten-point-plan-for-a-green-industrial-revolution-for-250000-jobs.ja)

In Japan, Prime Minister Yoshihide Suga declared a pledge for the country to become carbon-neutral by 2050 in his general policy speech in October 2020, with the country announcing its Green Growth Strategy through Achieving Carbon Neutrality on December of the same year. Japan needs to accelerate the implementation of measures to achieve carbon neutrality[9]. CN, however, cannot be achieved by simply promoting decarbonization of energy sources and electrification/motorization, but it requires initiatives in all directions. A carbon-neutral society entails the efficient sharing and use of various resources by multiple stakeholders. This means that it is imperative to achieve digital transformation (DX) and build a society premised on digitalization, i.e., Japan must realize Society 5.0 as proposed by the government. Moreover, Japan needs to realize carbon neutrality under uniquely difficult conditions; namely, (1) the difficulty of collaboration with other countries through sharing of gas pipelines and international power transmission lines, (2) the lack of areas suitable for renewable energy, such as having many mountainous lands and coastal areas with little shallow waters, and (3) the manifestation of problems associated with the decline in the working population (economic growth stagnation, regional depopulation, difficulty of maintaining social services, etc.). As a pioneer in taking on challenges, if Japan can realize Society 5.0 early on by setting milestones and implementing the proper PDCA cycle, then it will be in a position of leadership over other countries.

1.2 An Overview of the Energy Systems That Will Achieve Society 5.0

Society 5.0 is based on the information society developed through Society 4.0. Its aim is the realization of a rich society, achieved by simultaneously growing the economy and solving social issues, using systems that seamlessly integrate cyber (virtual) and physical (real-world) spaces[10]. Society 4.0 emphasized improvement of efficiency through scaling in response to population increase, and products, services, and processes were homogenized, resulting in uniformity of societal values. Problems, such as the unequal distribution of wealth and information (wealth–information concentration), vulnerability to natural disasters, and increases in environmental load, have come to the fore. Society 5.0 will pursue resilience and sustainability by overcoming these challenges through technological innovation, and by enabling diverse groups of people to exhibit diverse values. This type of society will enable collaboration among many stakeholders, as well as the sharing of previously fragmented information, the creation of

[9] In response to the EU Sustainable Finance Disclosure Regulation, the Minister of Economy, Trade and Industry (METI) compiled the Climate Innovation Finance Strategy 2020, which presents Japan’s approach in investments aimed at the realization of the SDGs and the goals set in the Paris Agreement (September 2020).

[10] The same issue is true regarding the challenges in achieving carbon neutrality, wherein the collection and sharing of stakeholder information/data in each of the processes of energy generation, transmission, and consumption leads to diversification of energy sources, smart demands, resilience, and the other new values.

new value (value creation), regional revitalization, and the establishment of energy systems distinct to each local community.

Also, recently, the experience of massive power outage due to Typhoons No. 15 and 19 in September 2019 led to a heightened awareness of the necessity and importance of having resilience. The COVID-19 pandemic has caused diversification of people’s lifestyles and abrupt changes in social conditions. These point to the stronger need for simultaneously realizing safety, security, and resilience, in addition to realizing carbon neutrality. Balancing carbon neutrality and resilience entails large-scale reforms in all the aspects of energy—production, distribution, use, and circulation—beyond electricity systems. This requires advanced integration of services, including information, transportation, and logistics. This integration must be agreed upon and participated by both the provider and recipient of services, pointing to the need for promoting reforms participated in by all members of society. All members here refer to the industry, academia, government, the various sectors, municipalities, corporations, organizations, and each and every individual of society. In regard to bulk power systems, there is a need to support decarbonization by promoting electrification, distribution of hydrogen and new fuels to support decarbonization of industries untenable to electrification, and decarbonizaton of energy sources. Further, the energy system as a whole must undergo structural reform for a stable and economically feasible realization of these changes to the bulk power system. The accelerated diversification of people’s lifestyles due to the COVID-19 pandemic also means that the transition to the “ideal form” of society that tolerates diversity is imperative. Energy data utilization will play a very critical role in realizing this transition, and will generate new values through the fusion of energy and services.

1.3 Changes in Japan's Electricity System and Challenges in Achieving Carbon Neutrality

Looking back on the history of power sector reform, there have been stepwise reforms since the 1990s, which aimed to maintain energy security while minimizing price increases, and expand options and business opportunities for consumers and businesses alike. As a result, new electricity suppliers have entered the field, including companies in other sectors, and the cost of electricity has gradually declined since 1995 until the Great East Japan Earthquake (post earthquake, electricity prices have increased because of changes in energy source configuration). In addition, full-scale liberalization of the retail electricity market started in April 2016. The range of consumer options has since expanded, as evidenced by the conversion rate among regular households to new forms of electricity surpassing 20% in December 2018. On the other hand, there have been limited investments in electricity systems since the earthquake and the shutdown of nuclear power plants, introduction of a fixed purchase price for renewable energy (feed-in tariff, or FIT), uncertain power demand in the future, and further weeding out of businesses from overhauls in the electricity system. This trend is exacerbated by the separation of electric power production and supply in 2020.

These changes and trends point to the necessity of preparing for worsening natural disasters, reviewing the methods for equipment formation and operation of power transmission facilities towards a shift to renewable energy as main energy source, and for measures to reduce the burden on citizens. In response, a wide-area power transmission master plan was presented by the Organization for Cross-Regional Coordination of Transmission Operators, Japan (OCCTO), and the Resilient Energy Supply Act was enacted in June 2020. Also, in December 2020, Japan's Hydrogen Roadmap was revised to include increasing the production capacity to 20 million tons annually by 2050 as part of initiatives to achieve carbon neutrality by 2050. Final adjustments were also made to the implementation of the government policy pushing for 100% share of EV in new vehicle sales by the middle of 2030.

As mentioned above, achieving carbon neutrality requires pursuing decarbonization initiatives across all sectors and in all directions, not only in the electricity sector. Electricity systems, however, play a crucial role in these initiatives, wherein they also play a role in providing diverse green energy sources, such as hydrogen and new fuels based on hydrogen, aside from continuing their conventional responsibility as the backbone of the energy supply. Chapter 2 discusses the technical problems in these directions presented by the government, and Chapter 3 and later chapters discuss concrete solutions to these problems.

Chapter 2 Role of Energy Systems in Achieving Carbon Neutrality in 2050

Achieving carbon neutrality in 2050 entails transformation of primary energy and industrial structures. The society that must be envisioned for 2050 should not only aim for achieving net zero greenhouse gas emissions, but should also take into consideration how society should change and what it should become as an integral part of human existence. In particular, the vision for society must consider how habitation and social welfare, transportation and employment systems, as well as administrative functions should look like 30 years from now. In Japan particularly, municipal governments are foreseen to face difficult circumstances with respect to finances and population composition in 2040. The private sector facilities and social infrastructures built during the high-economic-growth period will be almost half a century old by then, thereby needing replacement. This means that decarbonization strategies should be formulated in consideration of the need for more investments and of Japan's low level of self-sufficiency.

This chapter takes a look back on the analysis of scenarios for achieving 80% greenhouse gas reduction as discussed in Version 2 of the Proposal. Various concrete factors affecting the realization of carbon neutrality are outlined to offer opportunities for reaffirming the complexity of the issues at hand.

2.1 Vision for Energy Systems in a Carbon-neutral Society

(1) **Comparison of Hitachi-UTokyo's Technology Conversion Scenario and the Japanese government's Green Growth Strategy**

In the Version 2, we created four scenarios that include "decarbonization" (achieving an 80% reduction in domestic emissions, and reducing emissions worldwide using CO_2 credits) and "population decentralization" (concentration of population and industry in the suburbs of large cities such as Tokyo and Osaka, and distribution of the population across 60-70 medium-sized cities (union of higher-order regional cities) designated by MLIT). We applied the technology selection model[11] developed by the Fujii-Komiyama Laboratory at the University of Tokyo to quantitatively evaluate the Technology Conversion Scenario that called for population decentralization on the premise of the realization of the 80% reduction in CO_2 emissions. The decarbonization of the energy sources, progress in electrification, and optimization of energy use must occur simultaneously to meet CO_2 reduction targets. With respect to energy sources, variable renewable energy such as wind and solar power will be actively deployed primarily among

[11] The technology selection model is a type of energy/economic model that selects power generation technologies that minimize the cost of an energy system during a given period, with preconditions such as CO_2 reduction and upper limits to the deployment of power generation equipment.

local communities, accounting for 60% of power generation. When combined with hydropower, biomass, and others, the renewable energy generation output will reach 77%. With respect to energy use, there must be increased electrification in transportation and heat sources, such as EVs and heat pumps—a process that will necessitate a reform of energy networks. The electrification described above will increase the demand for electricity to 1,500 TWh (45% electrification rate) from 1000 TWh in 2013. We showed that investments in energy systems should be made assuming an increase in demand, by balancing economic growth and decarbonization through a positive cycle of growth and investment.

After these scenarios were presented, the Ministry of Economy, Trade and Industry (METI) formulated and announced the Green Growth Strategy through Achieving Carbon Neutrality in 2050 on December 2020. Figure 2-1 shows the data and targets for 2018, 2030, and 2050 under the Green Growth Strategy; the right side of the figure shows the relevant issues identified by Hitachi-UTokyo Laboratory. These issues will be discussed in detail in Chapters 3 and 4. As in the Technology Conversion Scenario, power demand in 2050 under the Green Growth Strategy is seen to increase by 30-50% from the current level as a result of electrification of the industrial, transport, and residential sectors. Likewise, with respect to the renewable energy output, the plan is to increase the total output from solar power, wind power, hydropower, geothermal power, and biomass by around 50-60%. Also, aside from maintaining nuclear/thermal power (with CO_2 recycling) at around 30-40%, power from hydrogen/ammonia is expected to be at around 10%. Figure 2.2 shows a comparison of the Green Growth Strategy and the Technology Conversion Scenario. The 80% CO_2 emissions reduction target is foreseen to be achievable through decarbonization mainly in the electricity sector. Achieving carbon neutrality entails omnidirectional measures that include both the electricity the non-electricity sectors, pointing to the crucial role of hydrogen and new fuels. Since these fuels can also be utilized in the electricity sector, i.e. as fuel for existing thermal power sources, the establishment of a value chain that effectively utilizes hydrogen and new fuels in different sectors will also lead to improvement in economic performance.

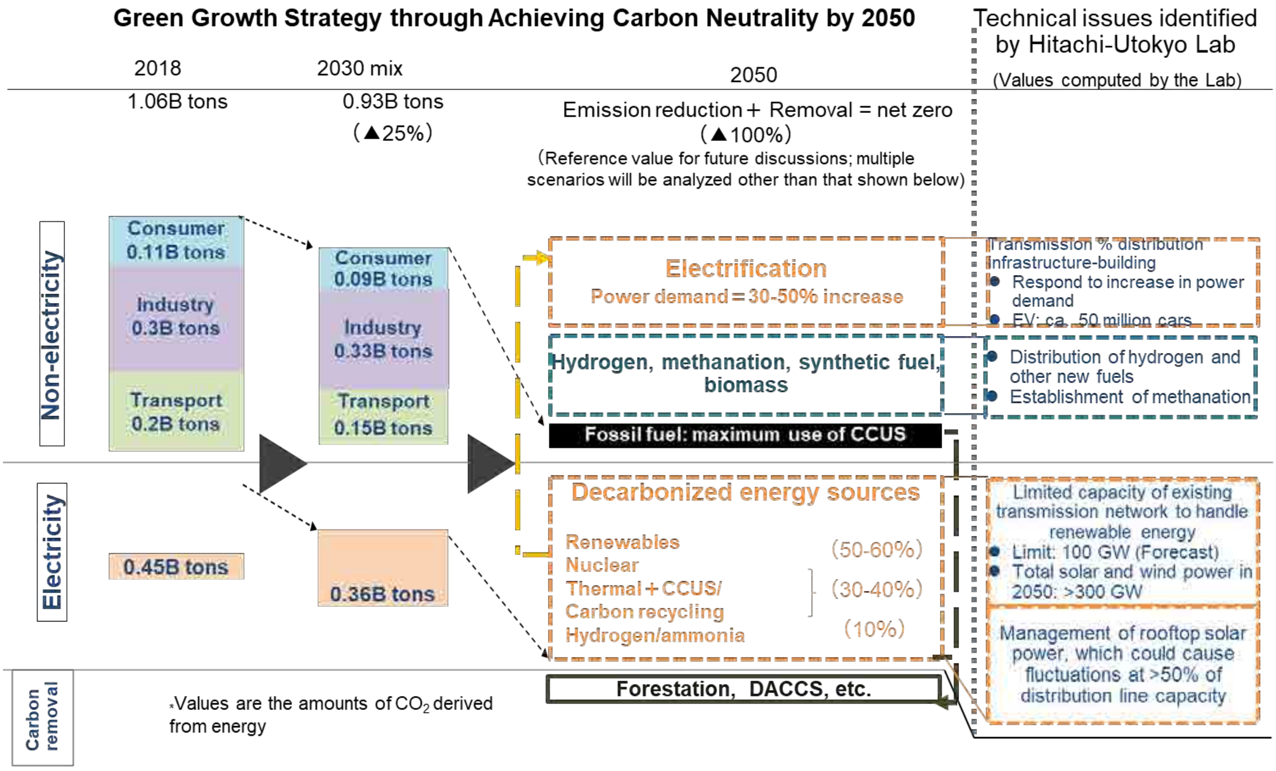
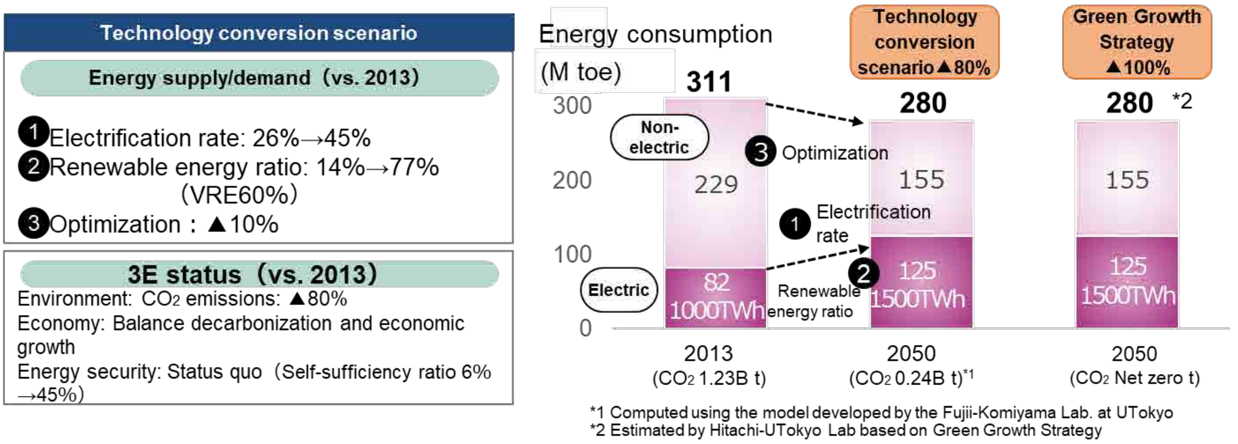


Figure 2-1. Directions of the Green Growth Strategy and technical issues identified by Hitachi-UTokyo Laboratory



2050	Total demand	Energy demand	Renewable energy	Other energy sources	CO_2 emissions
Technology conversion scenario	280 M toe	1500 TWh (ZEV/HP expansion)	77% PV: 20% Wind: 40%	23% Nuclear, etc.	20% Industry: 12% Transport: 6.5% Consumer: 1.5%
Green Growth Strategy	280 M toe	1500 TWh (Increase in electrification of non-electric sector)	50~60% PV: 14~16% Wind: 17-19%	40~50% Nuclear, thermal + CCUS, hydrogen/ammonia	Net 0% Hydrogen: 20M t, use of CCUS, etc.

Figure 2-2. Comparison of Hitachi-UTokyo Laboratory's Technology Conversion Scenario (Ver. 2) and the Green Growth Strategy

Remaining CO_2 emissions in the Technology Conversion Scenario is 238 M tons, whose breakdown is shown in Figure 2-3. While decarbonization is almost fully achieved in the power generation sector, further measures are needed in the industrial sector (ca. 60%), transport sector (ca. 30%), and the business/residential sector (ca. 10%).The ratio for the four major industrial materials (steel, chemicals, paper pulp, and cement) is 68%, pointing to the need for replacement of coal-dependent heat and energy sources mainly in these four major industries. The large ratio for "Others: boilers" indicates that there remains a dependency on fossil fuels in the small-to-medium-scale heat sources and industries using steam. In the transport sector, since plug-in hybrid vehicles have been selected in the calculations as the main choice, there is a fixed amount of CO_2 emissions from private vehicles. For aircraft and ships, and other sectors considered untenable to decarbonization, the use of e-fuels and other new fuels is being considered. Despite the progress of electrification of heating and cooling in the business/residential sector, there is a need for electrification measures for heat sources for supplying hot water and for cooking.

New carbon neutrality targets are being set as discussions on decarbonization in different countries are moving forward at a faster pace. Japan has recently presented concrete measures along with a roadmap towards achieving carbon neutrality in its Green Growth Strategy. Figure 2-4 shows the results of Hitachi-UTokyo Laboratory's calculations on energy composition in 2050. Figure 2-5 shows the results of approximations of the renewable energy deployment volume. The scenario shows that in 2050, electrification of non-electrified sectors and hydrogen production will be achieved through an increase in renewable energy deployment by more 3.5 times compared to 2030, and 3E+S will be ensured through centralization of energy sources, such as thermal power with CCUS, ammonia power, and nuclear power generation.

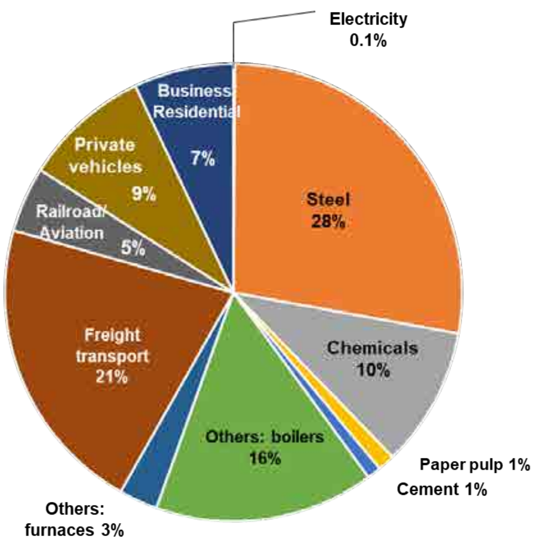
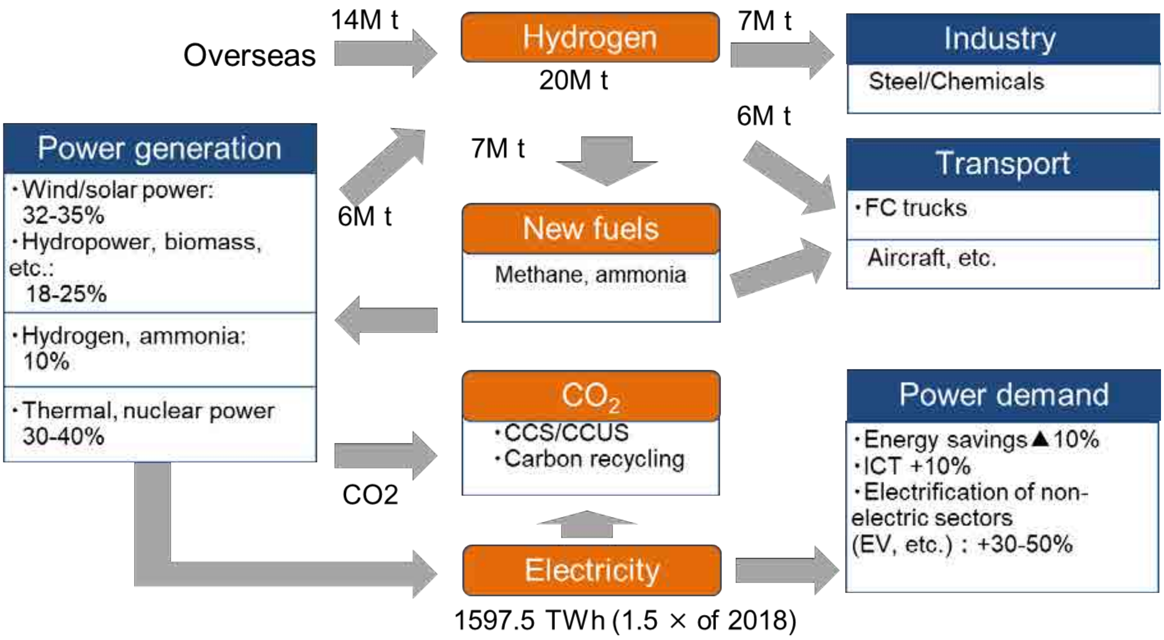
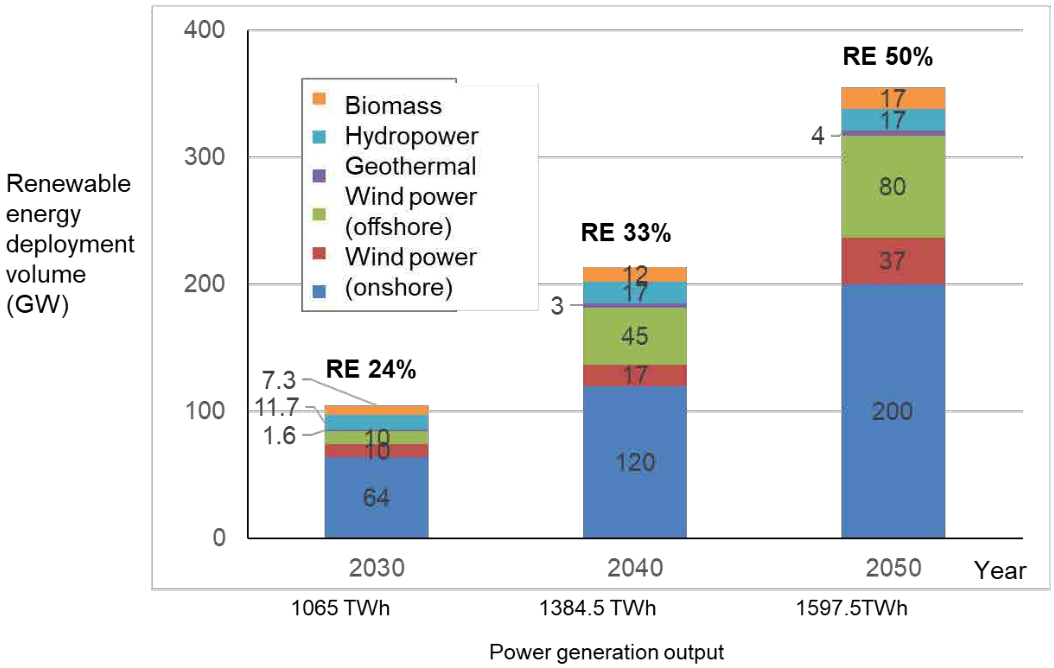


Figure 2-3. Breakdown of remaining CO_2 emissions in the Technology Conversion Scenario



*Values were partly computed by Hitachi-UTokyo Laboratory based on the "Green Growth Strategy through Achieving Carbon Neutrality in 2050"

Figure 2-4. Energy composition of the carbon-neutral society based on the Green Growth Strategy



*RE 24% represents the ratio of the renewable energy generation volume within the annual total power generation output (Wh)

Figure 2-5. Renewable energy composition example estimated from the Green Growth Strategy (Estimates by Hitachi-UTokyo Laboratory)

(2) **Social changes needed to achieve carbon neutrality**

Japan is forecasted to have a population of around 102 million by 2050, with children 14 years or younger at 11%, the working population (15-65 years old) at 52%, and the elderly population at 37%[12]. Population distribution in the Technology Conversion Scenario is premised on decentralization based on the Ministry of Land, Infrastructure, Transport and Tourism's (MLIT) Long-Term Plan. The following are the population trends inferred under this kind of population distribution. Regional hub cities with a population of over 200,000 will become the core of local communities and have the effect of stemming the steady movement of the population from the prefectures into the three major metropolitan areas to a certain degree (also called the "dam effect;" example shown in Appendix 1)[13]. The entrenchment of balanced operations between teleworking/working from home and working at the office brought about by the COVID-19 pandemic is fast-tracking the implementation of the long-term national land plans[14]. Once this decentralization comes into play, hub cities will become the regional and cultural centers over wide regions, enabling coexistence with neighboring towns and municipalities, paving the way to sustainability of industries and living spheres in each local community. Looking into the consumption of energy with respect to the decline in population (details in Appendix 1), we see that individual energy consumption in the residential sector and the private car transport sector is correlated with the population. There is a constant level of energy consumption, however, in the industrial sector and logistic transport sector, showing that there is little dependence on population in these sectors. We believe that by 2050, society will have been transformed into one where energy consumption and industrial structures unique to each local community are in an advanced level of coordination with renewable energies.

Hitachi-UTokyo Laboratory has proposed the enhancement of environmental and social values through natural-capital investments and society-related-capital investments in electricity systems and other social infrastructures towards a future vision of a networked infrastructure (water and sewage, roads, transport (railway and bus), and electricity) spreading across the entire local community in order to further enhance the people's Quality of Life (QoL)[15]. Building sustainable social infrastructures entails the creation of values from infrastructures based on data collaboration as well as the steady implementation of maintenance and rehabilitation operations. In other words,

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[12] National Institute of Population and Social Security Research, Population Projections for Japan (http://www.ipss.go.jp/pp-zenkoku/j/zenkoku2017/pp29suppl_reportALL.pdf).

[13] Refer to the White Paper on Regional Population Decline by the Hokkaido Intellect Tank (ISBN-13:978-4820120322) and other references for details on the population dam effect.

[14] Population trends under the COVID-19 pandemic are analyzed in detail by the MLIT Advisory Committee on Long-Term Prospects on National Land (https://www.mlit.go.jp/policy/shingikai/s104_choukitennbou01.html).

[15] Hitachi-UTokyo Laboratory. 2020. Proposal: Sustainable Social Infrastructure Management in Society 5.0 Era. http://www.ht-lab.ducr.u-tokyo.ac.jp/wp-content/uploads/2020/02/47d8e5dd1a8b24dd2123511399cf0bbc.pdf

building infrastructures by carrying out cross-sectoral analysis of various beneficial data on local communities will boost the sustainability of local communities.

We believe that focus on social infrastructure management will continue to become widespread. Through the Act on Special Measures Concerning Urban Reconstruction, the government is presently promoting new urban development under the initiative of organizations designated as Urban Reconstruction Promotion Corporations (associations, foundations, NPOs, corporations, urban development companies, etc.)[16]. New players like these organizations, therefore, will also become involved in energy management in local communities. To enable flexibility in these civic partnerships, the government is legislating laws to enable unified urban planning and regional infrastructure management, one of which is the power distribution licensing system.

(3) **Sectoral trends towards realizing carbon neutrality**

As mentioned above, the industrial sector accounts for approximately 60% of the 238 M tons of remaining CO_2 emissions in the Technology Conversion Scenario. Within the industrial sector, the four industrial materials (steel, chemicals, paper pulp, and cement) with large CO_2 emissions use carbon sources in their manufacturing processes and consume a large amount of heat energy. As many innovation options as possible, therefore, are needed for their transition to decarbonization. For example, in the chemical sector, naphtha (a raw material for key substances), is supplied on-site from petrochemical complexes in the petroleum refining process. A large supply of petroleum goes to the transport industry, namely, for airplanes, ships, and cars, which serve as the basic transportation means between cities. Fuel conversion in the transport industry, therefore, has a chain effect also on the chemical sector.

The chemical sector is a broad industry that covers production of four key materials (polyethylene, polypropylene, polystyrene, and polyvinylchloride) that are based on petroleum as raw material. These raw materials in turn are used for producing polycarbonates and other functional resins, as well as other high-performance materials such as resist materials needed in the manufacture of semiconductors. Current petroleum refining processes are geared at supplying gasoline, and naphtha is being imported to compensate for shortages. Meanwhile, production of ethylene, another basic raw material for many materials, has been slightly decreasing since 2015. Fuel conversion in the transport sector is seen to result in the following value-chain transformations in raw materials: (1) increase in naphtha import volume, (2) import and distribution of the four key materials as primary materials and re-processing of raw materials through

[16] The current Act on Special Measures Concerning Urban Reconstruction has set limits to operations, such as permission to occupy roads and riverbeds (Portal site for public-private partnerships on urban development: https://www.mlit.go.jp/toshi/seido/index.html)

plastic recycling, etc., or carbon cycling via material recycling to create high-performance materials through material re-processing, and (3) further development of C1 chemistry to synthesize functional materials using methane as raw material and raw material conversion based on methanation to produce methane from CO_2. Since material recycling and C1 chemistry require hydrogen as raw material, a stable supply of hydrogen and reduction in costs will be essential for these systems to be established.

Since carbon sources can be entrenched as products and can be distributed through quantity management, material recycling can be an effective means for decarbonization of society if a positive cycle can be achieved. Japan has a relatively high collection rate for waste plastics, with a high collection quality due to the cooperation of residents in cleaning and other initiatives. Material recycling, therefore, more strongly emphasizes the need for establishing collection mechanisms. Likewise, a reform in mindset among residents on waste elimination is also important from the perspective of reducing the burden on the environment.

Various forms of heat sources also exist in the industrial sector other than for the four major industrial materials, wherein decarbonization may be achieved through electrification of heat sources, improvement of thermal efficiency through process innovation, and use of methanation. Since most of these heat sources, however, are small or medium in scale, electrification will be the major means for decarbonization. Meanwhile, the increase in power demand following the heat-source conversion in the industrial sector will necessitate proactive coordination with electricity systems, making it imperative to effectively control these demands and their manufacturing plans.

The conversion to EVs and hydrogen-powered vehicles (fuel cell vehicle, or FCV) is seen as a plausible alternative for the transport sector. Coordination surrounding EV in the local community is discussed in detail in Chapter 3. The construction of hydrogen fuel stations, which is one of the hindrances in the uptake of FCVs, should be addressed by balancing the distribution of hydrogen and the utilization of existing facilities, such as hydrogen production facilities built mainly for petrochemical complexes and for trucks, buses, and other commercial vehicles. This should be done while reducing the cost of hydrogen production by utilizing surplus power from variable renewable energy.

Energy consumption measures in traditional cities have focused on energy conservation in equipment and facilities for heating, cooling, and supplying hot water for houses and buildings. Recently, however, more and more cities are aiming to change city lifestyles by building walkable cities like that in Barcelona, Spain, where walking spaces and bicycle parking areas are built to enable residents to move around the city centers by foot or by bicycle, signaling the changing mode of travel in cities. An example in Japan is the urban development project in Matsuyama City, Ehime Prefecture aimed at enhancing the accessibility of streetcars and widening sidewalks. Other than the increase in number of pedestrians, the project has demonstrated some positive ripple effects on the economy, such as increase in the number of nearby stores and rise in surrounding land value. A distinct characteristic of walkable cities is the shift in mindset from an automobile-centered movement to walking as a way of life, without the use of any means of mobility. This shift in mindset and the convenience it brings to residents are being planned into the building of walkable cities, pointing to the important role that data plays in urban development.

The use of hydrogen and synthetic e-fuels is being considered for decarbonization of aircraft and ships. Comprehensive systems for value-chain collaborations with other sectors and effective carbon utilization among sectors are necessary in ensuring economic performance and rationality.

2.2 Key Points for a Comprehensive and Cross-sectoral Process for Transition towards Carbon Neutrality

As mentioned above, Japan has to deal with many unique issues, such as its declining population, the need for replacement by 2030 of numerous basic social infrastructures and large-scale industrial facilities built during the high-economic-growth period, and the foreseen downsizing and financial contraction of local governments and their inability to provide proper services due to fiscal constraints by 2040[17]. These issues point to the need for a comprehensive management of the transition to carbon neutrality. These transitions must be carried out along multiple pathways that can be broadly managed under an overarching vision. The premises for these discussions are presented in detail in Chapter 6. Outlined below are the key points for this comprehensive transition process.

(1) Creation of long-term roadmaps through unified efforts of the industry, academia, and government

The transition to carbon neutrality will happen through coordinated changes in all sectors, such as the structural transformation of the petrochemical and other industries, reconstruction of the sprawling cities built during the high-economic-growth period, and fuel conversion in the transport sector comprising logistics, travel, and vehicles. These coordinated changes must be planned by determining the period and scale of transitions in each sector and in consideration of the effects on other sectors. Also, many of the technological innovations aimed at decarbonization are currently in the R&D phase, hence the long-term roadmaps for the development, deployment, and popularization

[17] The Ministry of Internal Affairs and Communication (MIC) Study Group on Strategies for Local Government in 2040 is carrying out discussions on a wide range of issues on local government operations until 2040 (https://www.soumu.go.jp/main_sosiki/kenkyu/jichitai2040/index.html).

of these technologies must be formulated by bringing together wisdom through unified efforts of the industry, academia, and government. Appropriate interim milestones must be set in advance to enable the verification and review of the long-term roadmaps[18]. Verification must be carried out based on data with quantifiable processes and therefore requires disclosure of such data. Likewise, consistent implementation based on verification results and suitable investments must be made.

(2) National land reforms in the "stock-type society" and utilization of existing basic social infrastructures

Due to the concentrated construction of social infrastructures during the high-economic-growth period in Japan, the country has an ample stock of infrastructures. In response to the decline in population, local governments have formulated regional location optimization plans as master plans for city planning[19]. These location optimization plans serve as master plans for encouraging long-term residency and optimizing the location of public facilities for a period of several decades. These changes in local communities and long-term national land visions should be organically linked with carbon neutrality policies and be synergistic with urban and national policy investments. In addition, the utilization of existing infrastructures, such as by combining existing city gas lines with methanation and converting them into energy transport infrastructures, must be studied as well.

(3) Cross-sectorally coordinated transition accompanying primary energy reforms

As mentioned above, a large-scale structural transformation of the petrochemical industry is needed in addition to electrification. Carbon cycling centered on the chemical sector; use of multiple energy storage formats, such as hydrogen, storage batteries, redox flow batteries, etc.; carbon cycling between the steel and chemical sectors; and other measures to secure materials and to cycle carbon must be comprehensively carried out. Meanwhile, the expansion of power demands due to electrification in different sectors will require coordination with electricity systems.

(4) Creation of transition processes enabling coexistence of resource circulation and value circulation

As stated above, a system for a straightforward explanation of the utilization status of advanced technological innovations for carbon cycling to final consumers will enable them to choose products based on those innovations. A

[18] During the Tokyo Forum 2020, it was pointed out that *"unless we reduce greenhouse gas emissions by half and become climate-positive by 2030, it will be too late,"* pointing to the importance of ascertaining our progress over the next 10 years.

[19] Ministry of Land, Infrastructure, Transport and Tourism (MLIT) Urban Planning—Location Optimization Plan System (https://www.mlit.go.jp/en/toshi/city_plan/compactcity_network.html).

positive cycle for economic consumption and transition to carbon neutrality will be achieved through a system that connects decarbonization products with consumers.

(5) Transitioning to carbon neutrality while ensuring convenience of city life

Data-driven management of cities has led to tangible and intangible changes in cities, such as that in the case of walkable cities, bringing about convenience to residents. These data-driven management approaches will also enable coordination between energy and people's lifestyles and behaviors, thereby leading to a reform in mindset towards carbon neutrality along with enhancing convenience and comfort.

2.3 Summary

- Realizing carbon neutrality in 2050 entails promoting electrification through the use of carbon-free power, structural changes in society as a whole including industrial sectors untenable to electrification, further development of current technologies, reform in people's mindset, and social structure transformation. It is economically important to create a value chain that will be used by various sectors, for example, utilization of hydrogen produced using renewable energy or secured through importation as fuel for power sources as well as in non-electrified industries and in long-distance transport.
- In the process of transitioning to carbon neutrality in consideration of the population decline and the age of social infrastructures, the following must also be considered: (1) creation of transition roadmaps through unified efforts of the industry, academia, and government, (2) effective utilization of existing basic social infrastructures, (3) cross-sectoral coordination accompanying primary energy reforms, (4) coexistence between resource circulation and value circulation, and (5) balancing convenience and carbon neutrality.
- By 2040, local governments will be in a difficult situation with respect to finances and population composition. By that time also, many of the country's social and private infrastructures will be more than half a century old, in addition to the paucity of Japan's resource environment and its low level of self-sufficiency. Japan, therefore, is aiming to realize carbon neutrality under a uniquely inhospitable environment. This calls for ensuring multiple technical and business alternatives, as well as multiple pathways towards achieving its social targets.

Chapter 3: New Challenges in Local Communities

In this chapter, based on the ideal state of local communities, we examine the current state of energy consumption and show the challenges involved in achieving carbon neutrality (CN). We will also examine the possibility of using energy data to create new value in the supply of energy.

3.1 The Ideal State of Local Communities, and What Should Be Changed

(1) The ideal state of local communities

In this proposal, the term "community" refers to an expansive area including the activities of residents such as industry, transportation, logistics, and medical care and education. The characteristics of such areas vary widely according to factors such as their population, area, geography, local industry and historical background, and from the viewpoint of energy use, it is preferable to work in harmony with these local characteristics. For example, large cities face issues such as high housing costs due to housing shortages, air pollution due to car exhaust, traffic congestion, wealth disparity, and increased crime, while small cities are affected by depopulation due to the migration of people to urban areas, and by financial difficulties in local government due to the declining productive population, which causes a serious decline in public services.

To address the problems of big cities, progress is being made in some cities (mostly in other countries) to introduce walkable city measures. A walkable city is one where people can access everything they needs without requiring a car. Some well-known examples of cities that have pursued this idea include Paris, Barcelona, Copenhagen, London, Portland and Hong Kong.[20] There are also plans to create walkable cities in Japan, where more than 200 local governments are working on road facilities and city center redevelopment projects that make it easier for people to move around. Walkable cities have a wide range of benefits, including reducing traffic accidents by cutting the amount of automobile traffic, helping local businesses by increasing the number of pedestrians, creating a livelier city atmosphere, extending the life of roads, bridges and other infrastructure by eliminating excessive dependence on automobiles, and cutting the amount of air pollution produced by road traffic.

In provincial cities, gentle plans based on a "compact x network" model are being promoted based on a government initiative.[21] By concentrating the main urban functions in the city center and enhancing the network functions of public transport such as trams and buses, the aim is to create towns where even elderly people who have difficulty driving can easily move around. There are also cases that make use of local resources. For example, in Shimokawa,

[20] The "15-minute city" plan in Paris and the "Superblock Project" in Barcelona are widely known as walkable cities.
[21] Ministry of Land, Infrastructure, Transport and Tourism: Priority Measures — Compact Plus Network. https://www.mlit.go.jp/toshi/toshi_ccpn_000016.html

Hokkaido, biomass derived from the abundant local forest resources are being used to supply the town with heat energy, and tenement-style houses are being built as residential communities for elderly people.

Walkable cities and compact cities are suitable policies to adopt in areas that consist of flat land. However, in Japan, where about 70% of the land consists of hills and mountains, and where towns and residential areas have been built up over a wide area, it may also be necessary for town planners to consider leaving people with the option of car use. Local energy systems contribute to the creation of comfortable cities by rebuilding them according to various community development policies.

On the other hand, local communities are also changing due to recent upheavals such as natural disasters of increasing severity, the COVID-19 global pandemic, and the CN Declaration. The increasing severity of natural disasters is increasing the demand for and importance of energy resilience in local communities. With the Japanese Government's call for people to prevent the spread of COVID-19 by avoiding the three 'C's (closed spaces, crowded places and close-contact settings), there are signs of decentralized use of public transport, increased use of automobiles, and a growing need for workplaces that are close to the home to facilitate working in residential areas, and social changes are already taking place in cities whereby the movement of people is being replaced by the movement of goods and services.

With regard to CN, decarbonization is changing from simply a way of improving corporate image to an essential requirement for achieving business continuity and acquiring loans, and it is becoming essential for local businesses to provide environments that support the decarbonization of local communities. The energy infrastructures of communities must be restructured to accommodate these changes.

Since CN involves reforming society as a whole, it is essential to build consensus among all the stakeholders of society in order to implement these reforms. The size, population structure, existing resources, and visions of cities differ from one region to the next, and they are also subject to different restrictions on the availability of financial resources to achieve this transition. Therefore, if local communities are to achieve CN, they must be able to provide enough value to gain consensus from stakeholders by creating a mechanism to resolve social transitions and issues specific to the region, and they must improve their resilience while reducing the cost and duration of community transitions by efficiently sharing and operating diverse resources among multiple stakeholders under diverse conditions. To meet these requirements, in addition to implementing various community development measures, it will be necessary to adopt smarter and more diverse energy resources, which means it will be necessary to construct energy data utilization systems (Figure 3-1).

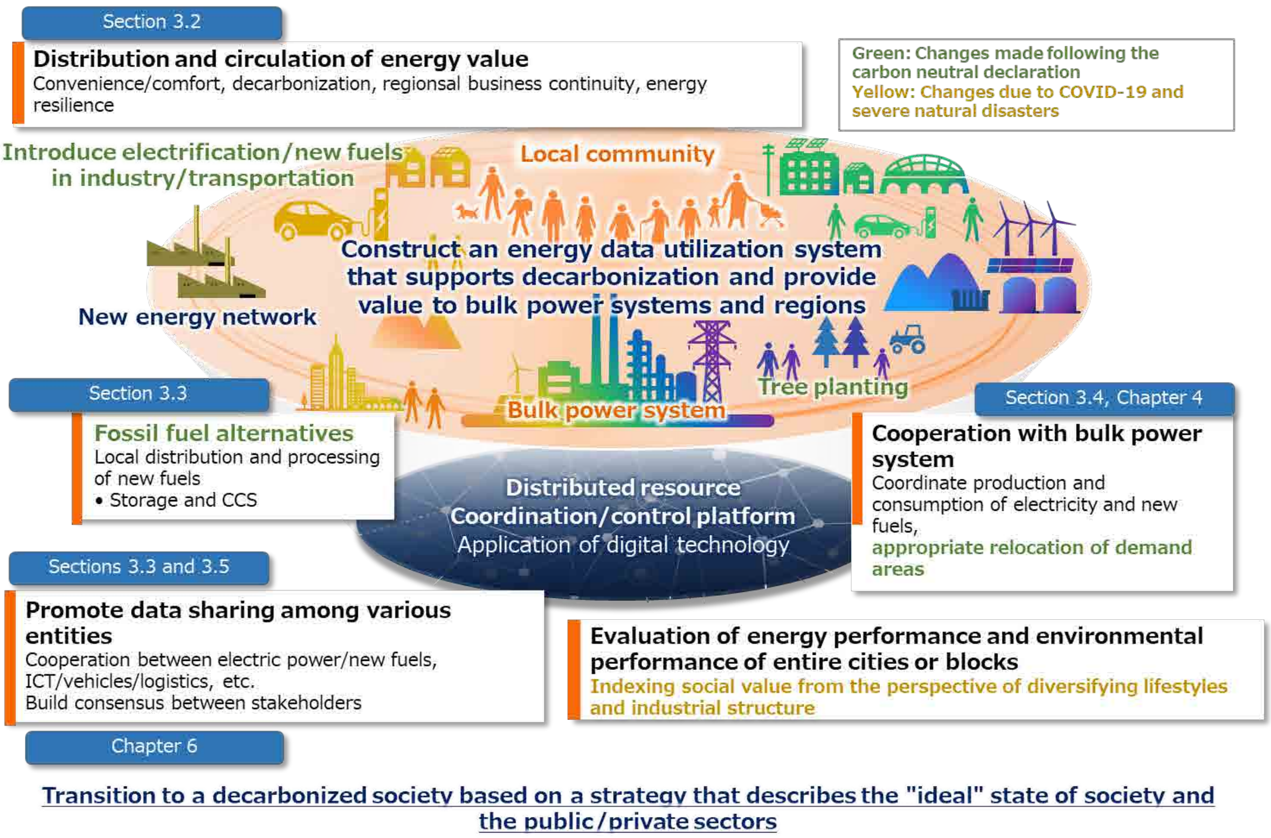


Figure 3-1: What communities should do to achieve CN

(2) Reforms aimed at achieving the ideal state of local communities

Figure 3-2 shows the direction indicated by the green growth strategy and the technical issues faced by local communities. The data shown for 2018, 2030, and 2050 corresponds to the details given in the green growth strategy, and the technical issues listed on the right side of the figure were identified by Hitachi-UTokyo Lab based on disclosed information.

In the consumer, transportation, and industrial sectors, the introduction of electric power is the basic approach to decarbonization. This is particularly so in the case of automobiles in the transportation sector. There are currently about 66 million passenger cars in Japan, and based on the progress of compact city initiatives and car sharing, it is expected that about 50 million electric vehicles (EVs) and fuel cell vehicles (FCVs) will be on the road by 2050. In a CN society, photovoltaic power generation will be an inexpensive source of energy, and it will be possible to store solar power in standard consumer equipment by reverse power flow. In this case, in electric power distribution systems, the increased demand caused by the switch to EVs and other electrically powered devices and the reverse flow of solar power results in flows of increased complexity in power feeder equipment, which raises the issue of providing an electricity distribution infrastructure that maintains a stable supply of electric power. Furthermore, in the industrial sector, although electrification is promoted, it is difficult to achieve in applications such as blast furnaces that require large amounts of heat, and new forms of fuel distribution such as methanation are becoming a major issue.

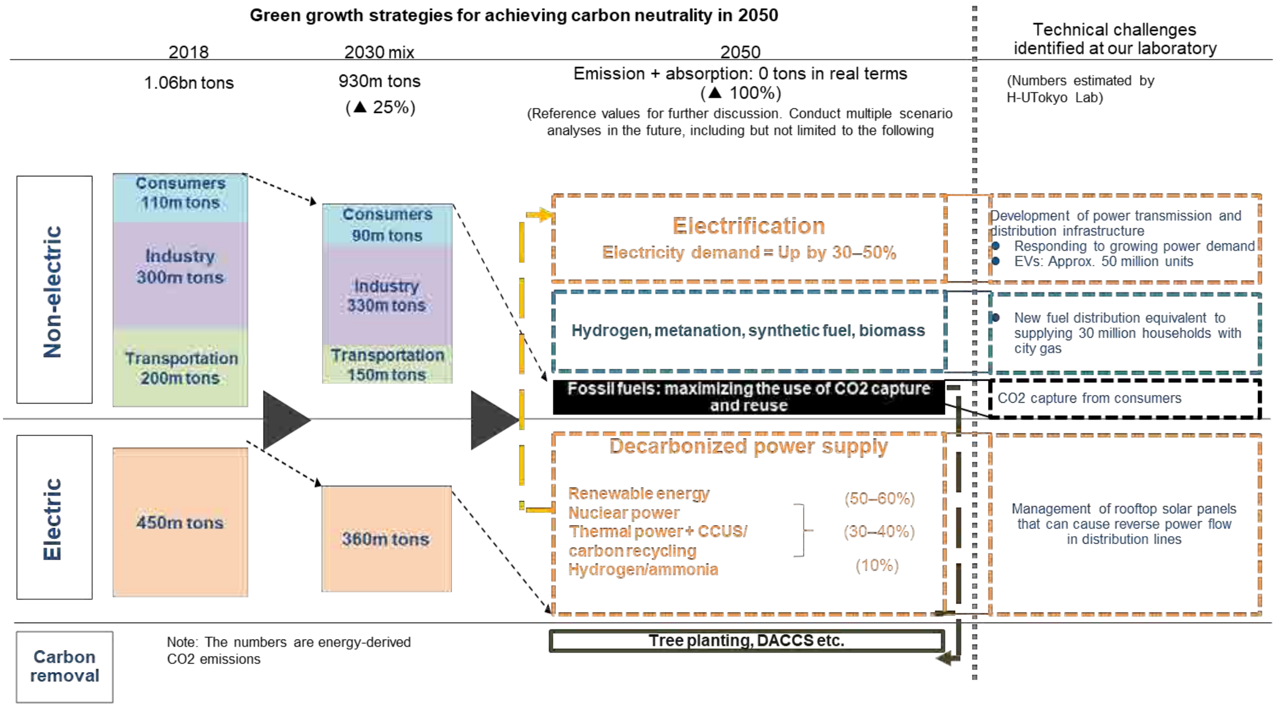


Figure 3-2: Direction indicated by green growth strategy and technical issues from the viewpoint of local communities

Figure 3-3 shows how local communities should adapt with change drivers in mind in order to respond to the issues identified above. Newspapers and other media have reported that the proportion of electric vehicles in new car sales will reach 100% by the middle of 2030. Casting back from this timing, energy data utilization systems will be installed in the power network corresponding to distributed resources such as large-scale electrification systems and electric vehicles that are becoming increasingly common. Furthermore, photovoltaic power generation will be installed as standard in homes. These changes will determine the specifications of the various connected technologies, so it is desirable to determine these specifications as soon as possible and build them in advance, including allowances for trial periods. It is also expected that hydrogen and new fuels will be introduced and grow in popularity towards 2050, and it will be necessary to build systems for the manufacture, distribution and use of fluctuating energy sources such as solar power and wind power so they can be put to maximal use.

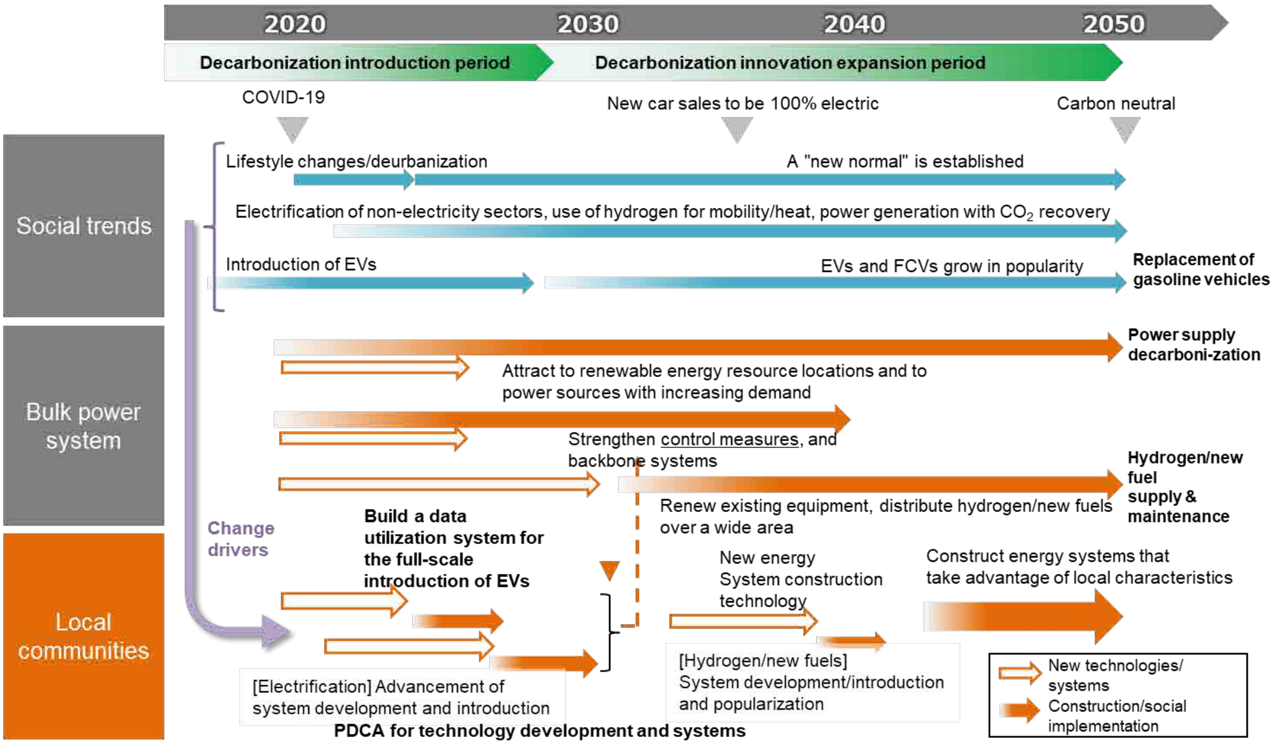


Figure 3-3: Changes in communities with the awareness of change drivers

To promote the transition of local communities that require urgent and long-term involvement with limited finance and resources, energy services to consumers will have to be provided via a bidirectional, inexpensive and highly reliable energy supply, and it will be necessary to provide coordinated services from the consumer side to the energy supply side that make the best use of existing assets (Figure 3-4). By developing legal systems and equipment requirement standards (Grid Code) that support the functioning of energy data utilization systems, and by establishing and operating mechanisms and systems that are predictably and incrementally improved while reaping benefits with various stakeholders, it is possible to achieve a virtuous cycle of investment, benefits, and reinvestment that changes social systems while benefiting society as a whole.

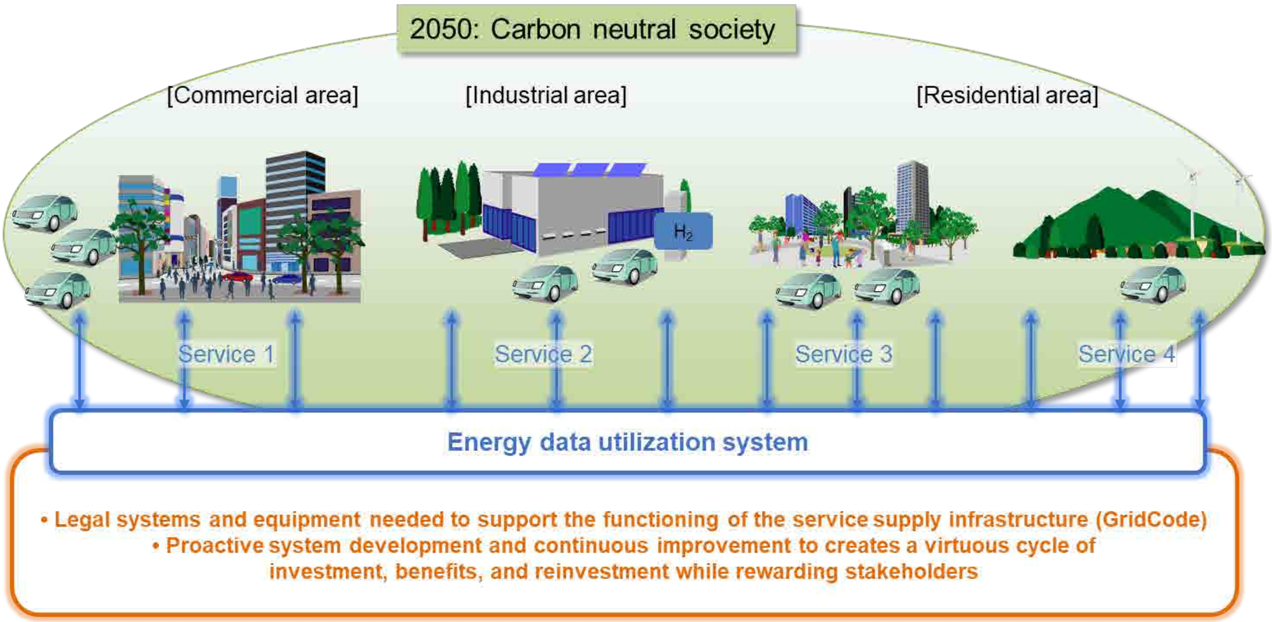
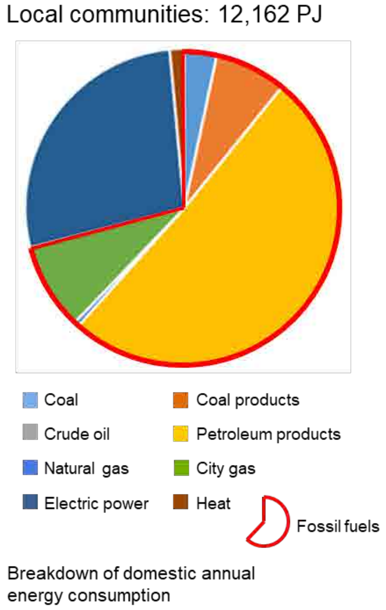


Figure 3-4: Energy data utilization system that supports a CN society

3.2 Regional Energy Consumption Characteristics/Issues, and Energy Data Utilization Systems

(1) Characteristics of regional energy consumption

In 2019, about 70% of the energy consumed in Japan was obtained by burning fossil fuels. Most of this took place within local communities where it was used by factories, automobiles and heating systems. Figure 3-5 shows a breakdown of energy consumption and the major CO_2 emission factors in the industrial, transportation, and consumer sectors. The main sources of emissions are the combustion of fossil fuels for heating in industry and by private consumers, and in automobiles used for transportation. The introduction of EV automobiles and the electrification of boiler heating systems should be started in advance to promote decarbonization by enhancing existing technologies. On the other hand, in industries that use high temperature processes requiring large amounts of heat, it is difficult to switch completely over to electricity. For energy demands of this sort, the recovery and utilization of CO_2 from exhaust gases ultimately resulting from fossil fuel combustion should be considered as an option.



Major CO2 emission factors and decarbonization measures for non-electrical equipment

	Main factors	CO_2 [×10^6 t]*1	Decarbonization measures
Industry	Furnaces	158 (34.0%)	• Hydrogen reduction (steel) • Replace with new fuels, e.g. metanation • CCUS in coal furnaces • **Switch to electric heaters***
	Boilers	63 (13.4%)	• **Switch to electric heaters*** • Replace with cogeneration using non-carbon-emitting fuels
Transportation	Aviation/shipping	20 (4.3%)	(Improve efficiency by partial electrification)
	Automobiles	142 (30.3%)	• FCV for long-distance vehicles • **EV for short-distance vehicles***
Consumers	Heating	24 (5.2%)	**Switch to electric heaters***
	Hot water	17 (3.8%)	

*1 Estimated value of non-electrical equipment in 2030

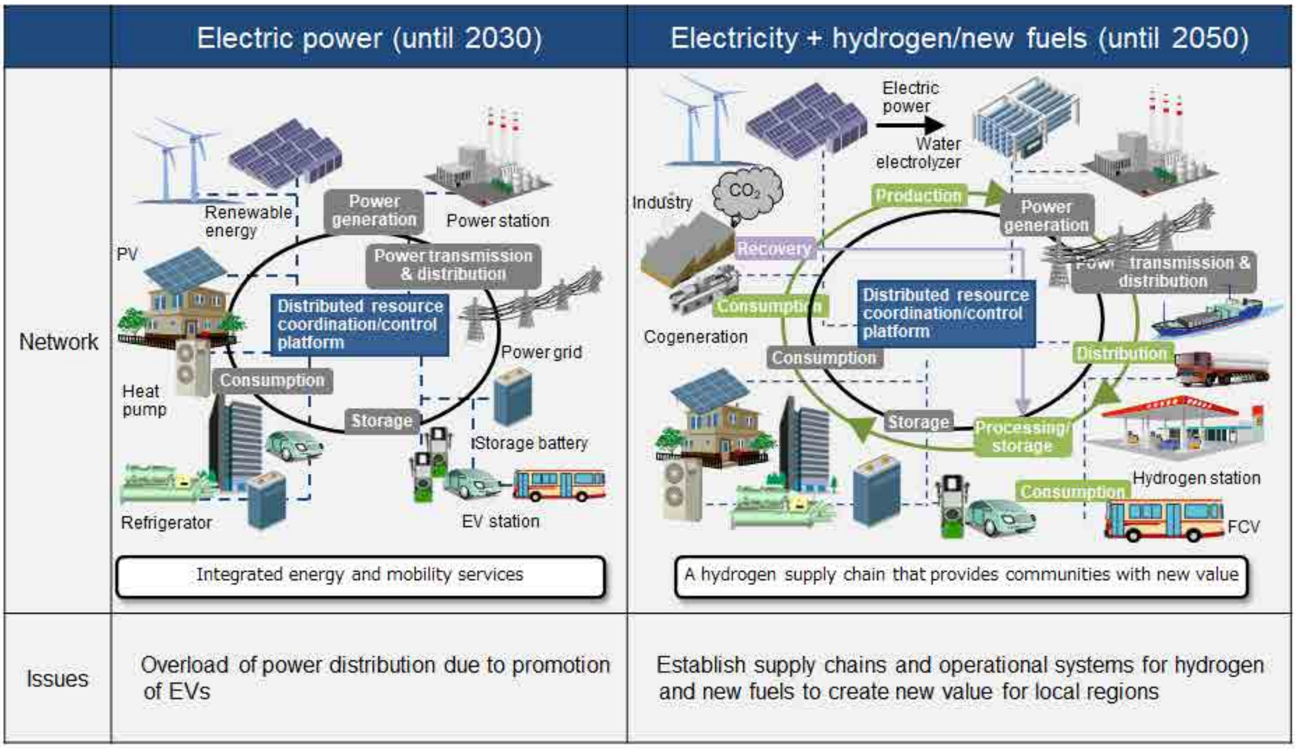
*** Priority items**

Figure 3-5: Breakdown of energy consumption and principal CO_2 emission factors by sector[22]

(2) Decarbonization issues in local communities, and the solution of issues through value circulation

Figure 3-6 shows an energy network that achieves decarbonization. Although gas and oil will continue to be used until the 2030s, the main infrastructure for energy supply and demand will be the electricity power grid. As progress is made in the electrification of automobiles, electric power and automobiles will become closely related, and local communities will start to provide services that combine energy and mobility. Furthermore, to handle the increased electricity demand caused by electrification, it will be important to ensure that the distribution network that delivers power to local communities can operate efficiently and avoid becoming overloaded.

[22] The pie chart is sourced from the fiscal 2019 simplified table in the Agency for Natural Resources and Energy's "Aggregate or Estimated Results" (Comprehensive Energy Statistics). https://www.enecho.meti.go.jp/statistics/total_energy/results.html#headline1)



PV: Photovoltaic power generation

Figure 3-6: CN networks and the issues that need to be addressed

By 2050, hydrogen and new fuels will become important energy resources, and supply chains for these fuels will be constructed to accommodate both imports from overseas and domestic production using excess power from the expanding renewable energy sector, allowing them to be used for diverse applications to create new value in local communities. Investment is needed to build these supply chains, and value creation initiatives commensurate with this level of investment are also required.

The system proposed herein as a means of solving the above problems is the distributed resource coordination and control platform (Figure 3-7), which forms the core of the energy data utilization system. The distributed resource coordination and control platform supports the utilization of distributed resources, realizes efficient use of distribution networks and provides bulk power systems with the capacity to adjust, facilitates stable and efficient use of electric power and energy under normal operating conditions in local communities, and improves the resilience to disaster situations. In a society where hydrogen and new fuels are widespread, mutual cooperation between different energy carriers will provide new value to local communities through energy mobility services, thereby providing value to bulk power systems and other regions. To deliver this value, the distributed resource coordination and control platform will cooperate with individual distributed resources, core energy systems, and services such as MaaS

(Mobility as a Service) platforms, and in addition to routine cooperative operation, it will also contribute to future designs based on the analysis and accumulation of collected data.

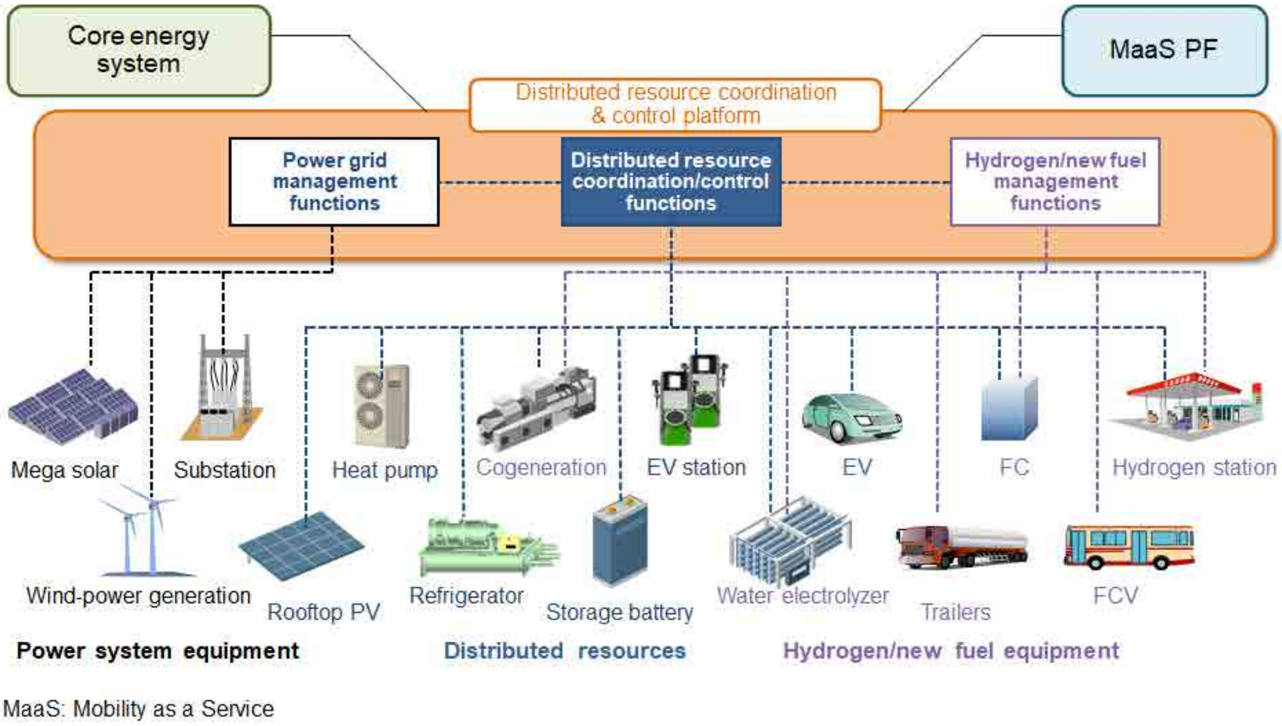


Figure 3-7: Overview of the distributed resource coordination and control platform

3.3 Solving Energy Network Issues with an Energy Data Utilization System

This section introduces some examples of how value creation by a distributed resource coordination and control platform can solve technical issues in electric power networks in the 2030s and in electric power + hydrogen/new fuel networks in 2050.

(1) Solving problems in electric power networks in the 2030s

With the spread of EVs and the progress of MaaS as represented by automated driving, the 2030s will be an era in which mobility and electricity are closely related. These two services will create value for each other by cooperating through the distributed resource coordination and control platform based on a change in the consciousness of both service providers and service receivers (Figure 3-8).

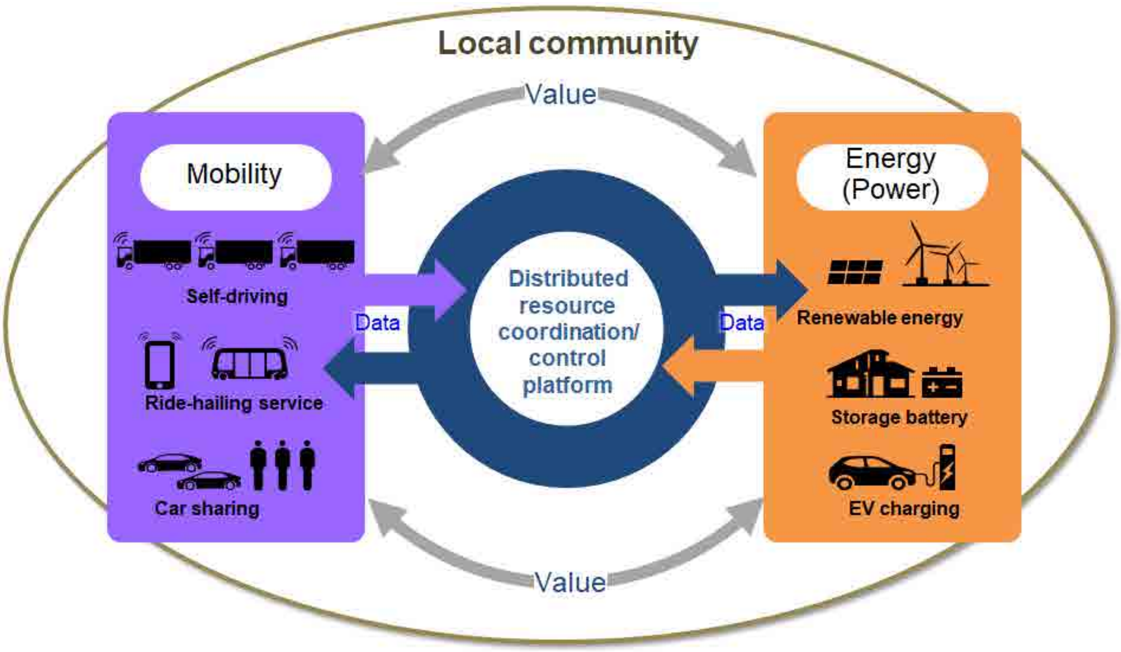


Figure 3-8: Creating value for local communities through the fusion of electricity, energy and mobility services

We will consider the impact of the spread of EVs using residential areas as an example. Suppose there are 7,000 households connected to one transformer bank in a distribution substation. In communities where EVs are widespread, there will be almost as many EVs as there are households connected to this transformer bank. If we assume that the maximum power consumed by an EV with a normal charger is about 3 kW,[23] then 7,000 households will consume 21 MW if they all charge their EVs at maximum power at the same time. In reality, EV charging demand is controlled so as not to exceed the domestic amperage limit. With this demand control in place, the average power consumption can be restricted to about 3 kWh per day, averaging 0.5 kW over 6 hours, so the total power consumption of 7,000 households will be 3.5 MW. The transformer capacity of a typical distribution substation is 10 to 20 MVA, so this increase in power consumption corresponds to between 15% and 30% of the transformer rating. In addition to this, progress will also be made with the electrification of equipment such as heat pump type water heaters (HPs). When the power consumption of EV charging and HPs is added to the conventional power consumption, it could overload the distribution network, causing major problems due to the current capacity overload and voltage fluctuations. As shown in Figure 3-9, the distributed resource coordination and control platform distributes coordinated information based on people's lifestyles to demand equipment via the information network, and shifts the time zone of power consumption to eliminate overloading.

[23] See Nissan Motor, "Nissan LEAF Major Equipment List":
(https://www3.nissan.co.jp/content/dam/Nissan/jp/vehicles/leaf/2010/pdf/leaf_specsheet.pdf)

Figure 3-10 shows an example of analysis performed by the distributed resource coordination and control platform to avoid overloading the substation. (Details of the model construction and quantitative evaluation can be found in Appendix 2). By adjusting the charging times in consideration of HP boiling and EV use during daytime shifts, it is possible to maintain the convenience of consumers, avoid overloading the substations, achieve stable operation of regional distribution networks, and eliminate or delay the need to enhance the substations and the entire distribution network.

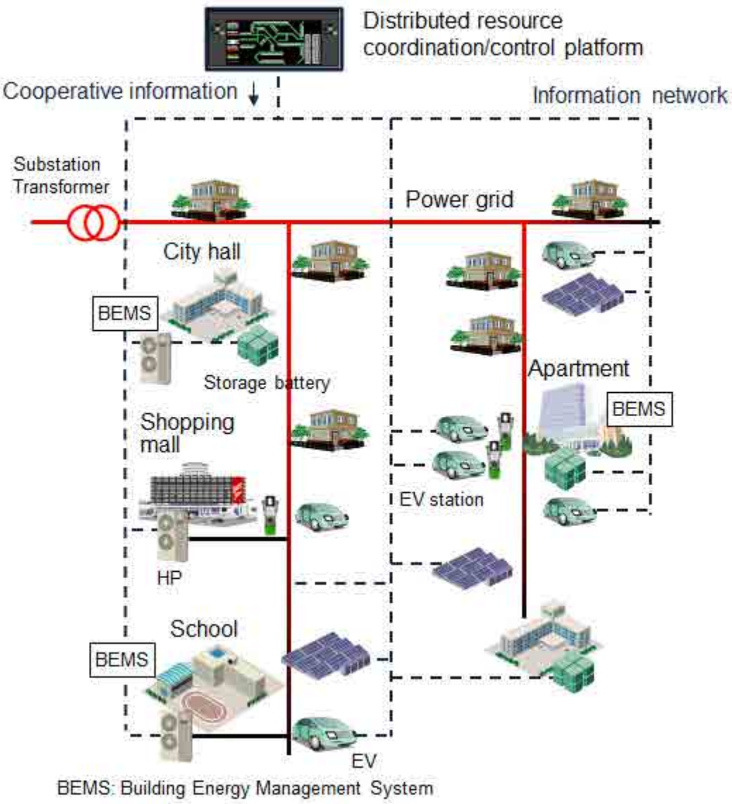


Figure 3-9: A system for the coordination of demand and equipment based on a distributed resource coordination and control platform

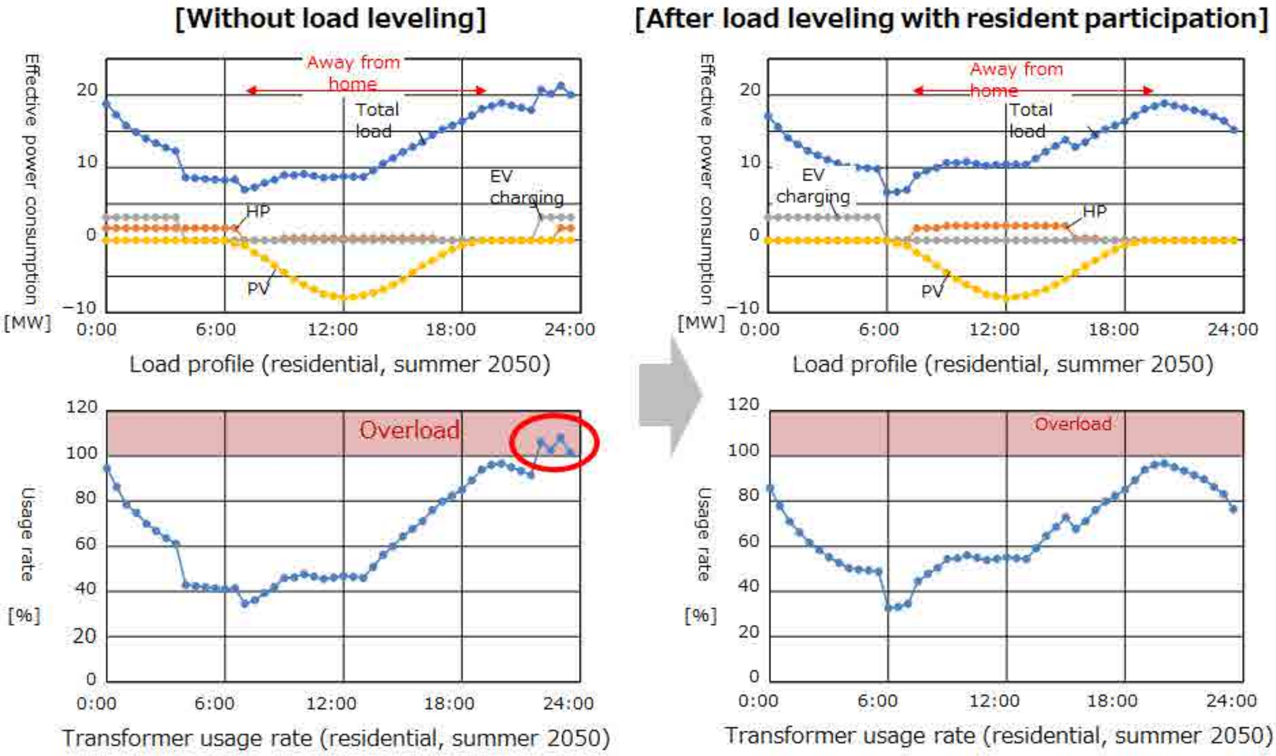


Figure 3-10: Example of substation overload avoidance by a distributed resource coordination and control platform

There are multiple possible values that can be obtained through the coordination of electricity and mobility (Figure 3-11). In addition to operating distribution networks stably by avoiding substation overloads and eliminating or delaying the enhancement of distribution facilities as described above, it will also be possible to provide a variety of values, such as reducing electricity rates by supporting real-time pricing, ensuring resilience by constructing autonomous areas in the event of a disaster, and supporting the introduction of renewable energy by providing bulk power systems with adjusting capacity.[24] In this way, a distributed resource coordination and control platform can provide value to the distribution networks of local communities, to local residents, and to bulk power systems.

By maintaining and improving these benefits, allowing energy to be used stably, controlling costs, and securing sources of income, we will be able to secure and improve the economic efficiency of local governments that provide services over distributed resource coordination and control platforms and of distribution companies that use distribution licensing systems, ultimately leading to added value for local residents.

[24] The United Kingdom is working on the Power Potential Project, a demonstration of a regulating power market based on distributed resource aggregation under power distribution.

Means	Description	Value recipient
Introduce electrification and renewable energy to avoid the need for investment in stronger power distribution	Eliminate overloads by using distributed resources	Power distribution
Reduction of electricity charges corresponding to real-time pricing	Use EV storage to enable purchasing of electricity during cheaper periods (*1)	Local residents
Reducing the cost of ensuring resilience	Use distributed resources to build an autonomous system for disaster management (*2)	
Entry of local regions into the adjusting capacity market	Entry into the adjusting capacity market through aggregation (*3)	Bulk power system
	Address projected shortfall of renewable energy due to shortages of solar radiation and wind power	

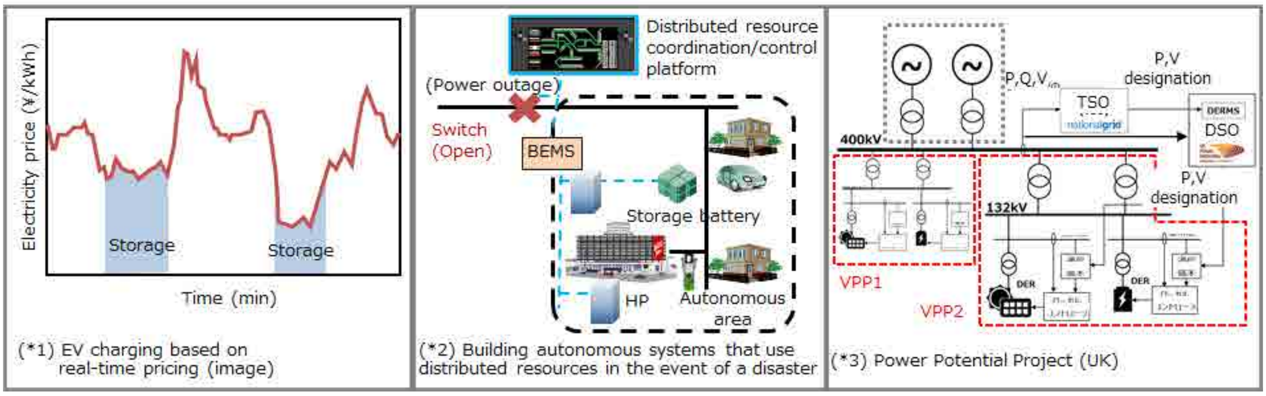


Figure 3-11: Distributed resource coordination and control platform (power-mobility)

(2) Solving problems with electricity/hydrogen/new fuel networks in 2050

For hydrogen and new fuels (the new energy carriers), the challenge is to build a supply chain that encompasses everything from production to distribution, storage, utilization, and (if necessary) recovery of CO_2 after utilization. On the other hand, an example where new value is created in a local community by coordinating different energy sources is described below.

In the society of the 2050s, when hydrogen and new fuels have become widespread, data-driven distributed resource coordination and control platforms will be used to create new value from electricity, mobility and hydrogen/new fuels. A concrete example of value creation is illustrated in Figure 3-13.

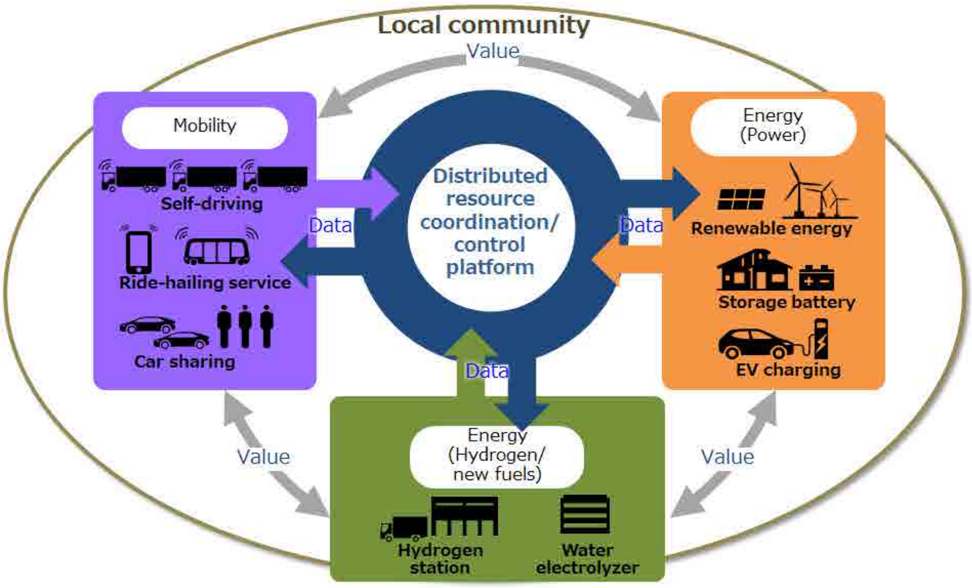


Figure 3-12: Creating value for local communities through the cooperation of different energy sources and fusion with mobility services

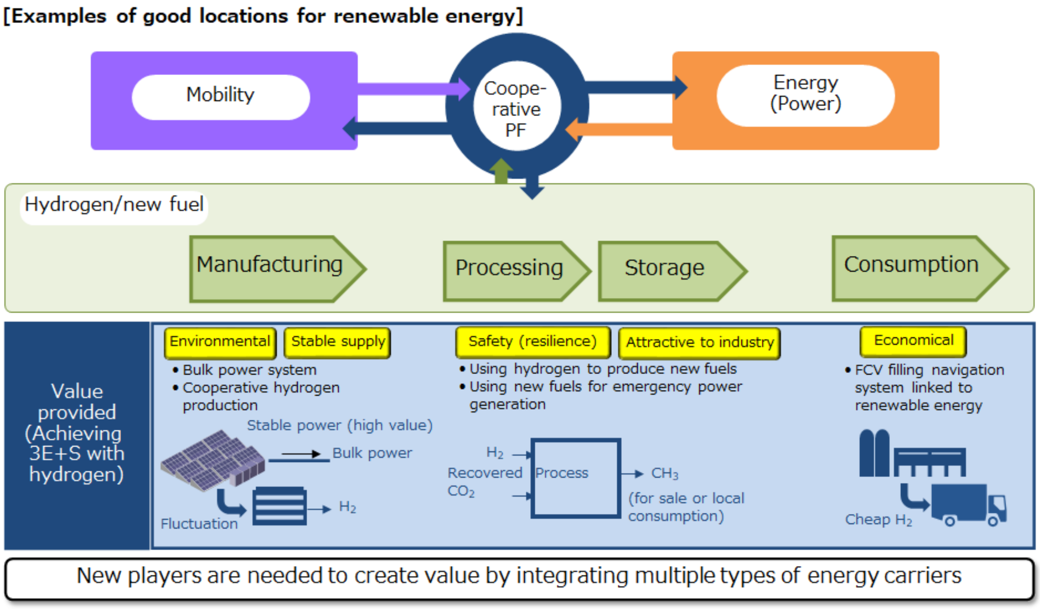


Figure 3-13: An example of value creation through digital transformation of the hydrogen supply chain

In areas where renewable energy is located, the production of hydrogen can be coordinated with fluctuations in renewable energy output to link bulk power systems with a supply of electricity that varies little, thereby creating value through the environmental, economic and stable supply of hydrogen/new fuels and electricity to businesses. It is also possible to construct a carbon cycle, such as by producing methane from recovered CO_2 and hydrogen.

Hydrogen and new fuels generated from VRE energy sources such as solar and wind power are constitute so-called "green" fuels, which have the advantage of causing no net CO_2 emissions when they are burnt. On the other hand, like conventional fossil fuels, these fuels must be handled carefully as they are highly flammable substances that ignite easily. In the case of hydrogen, it is difficult to construct and maintain a cryogenic atmosphere for liquefaction or a high-pressure atmosphere for compression, and thus large-capacity, long-term storage remains an issue.[25] Methane also incurs energy losses during production and creates CO_2 emissions during use, but its storage constraints are not as great as for hydrogen. In the future, if we can select new fuels that are more suitable for long-term storage, it will be possible to store them as a backup against seasonal fluctuations in renewable energy and for emergency power supply in times of disaster, thus making the supply of energy more resilient.

If a region already contains industries that use new fuels and is able to attract other new industries that also use new fuels, then economies of scale can be expected. In addition, if, for example, a filling station navigation service is developed to encourage people to fill up with hydrogen based on information about renewable energy generation, it would allow fuel cell vehicles to be provided with inexpensive hydrogen, thereby achieving economic benefits.

In this way, new value can be created by using data to coordinate different forms of energy and mobility. However, to realize such communities, new players are needed to design and operate new community styles in partnership with local governments in order to create value by integrating multiple energy carriers and services. The areas suitable for renewable energy locations are limited, and in many areas, the energy supply will achieve a combination of economic growth, energy security, environmental protection and safety ("3E+S") by complementing the values offered between different regions.

3.4 Cooperation with Bulk Power Systems

In the CN society of 2050, energy will be provided by multiple carriers of electricity, hydrogen and new fuels, and energy will mostly be obtained from variable renewable energy (VRE) sources. The power generation output of VRE fluctuates with changes in solar radiation and wind speed. Although the supply of adjusting capacity is still traded in the market to coordinate demand and generation, coordination capabilities will play an even more important role in a CN society, where it will be necessary to procure and alter adjusting capacity over a long period of time, ranging from short time units to long time periods, even spanning across entire seasons.

In some countries and regions, real-time pricing has been introduced as a means of obtaining adjusting capacity in a short period of time through the market, and the Electric Reliability Council of Texas (ERCOT) is operating a wholesale market where the unit price of electricity changes every five minutes. By coordinating

[25] Agency for Natural Resources and Energy: Hydrogen production, transportation & storage. https://www.meti.go.jp/committee/kenkyukai/energy/suiso_nenryodenchi/suiso_nenryodenchi_wg/pdf/005_02_00.pdf

the electricity demand of local communities through the distributed resource coordination and control platform, and by operating EVs and other power storage systems in conjunction with real-time pricing, a bulk power system can create demand during times of energy surplus, and the local community can purchase electricity at low rates.

In addition to the short-term supply of adjusting capacity as described above, it is possible to arrange the demand for hydrogen production and the like close to VRE grid interconnection points, thereby stabilizing the bulk power system and avoiding the need for grid expansion. As explained in detail in Chapter 4, it is expected that achieving CN will involve the production of 6 million tons of hydrogen per year in 2050. If we assume that this electricity consumption includes the production of hydrogen by water electrolysis, then spatial coordination of this new energy demand and VRE may help to solve the problem of decarbonization.

3.5 The Importance and Issues of Data Sharing between Various Infrastructures and Devices

As progress is made with infrastructure replacement and integration amid the growing trends towards decentralization, digitization and electrification/motorization, it is becoming necessary to utilize the information technology of conventional field-specific management systems to achieve high efficiency and high added value.

On the other hand, rebuilding the information collection system of each business from scratch requires a lot of time and heavy investment. Existing information collection mechanisms should therefore be used when appropriate. In smart cities, a system is adopted in which data is collected for each business division equipped with a common communication interface, and is integrated by a data linkage platform (city OS). This linkage platform could also be used as one option for accelerating the implementation of data utilization as a means of connecting different businesses in the distributed resource coordination and control platform (Figure 3-14). Since privately owned devices such as EVs are also subject to coordinated control, the secure handling of personal information is vitally important. In addition, a distributed resource coordination and control platform doesn't just collect and processes information, but also has a direct effect on energy operations in the physical domain, so it is also important to provide physical security in addition to guarding against information leakage. of data free flow with trust (DFFT)[26] to ensure secure and trustworthy data access, and the organization of risk sources and response policies into a cyberspace layer, a physical space layer, and an intermediate layer that transcribes cyber and physical data in order to

[26] Information and Communication Technology (IT) Strategy Office, Cabinet Office, Government of Japan, 2018: "Outline of the New IT Policy Framework for the Digital Age" (Draft). https://www.kantei.go.jp/jp/singi/it2/dai76/siryou1-1.pdf

implement security provisions.[27] It is also necessary to promote discussions of safety assurances from the viewpoint of energy control, and to promote data collection in parallel with feedback in actual projects.

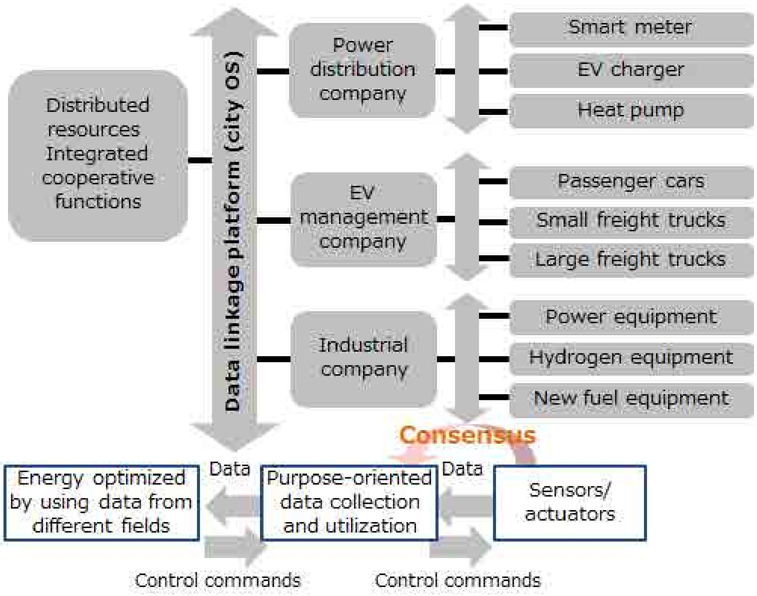


Figure 3-14: An information sharing structure with a wide variety of devices in an energy data utilization system

3.6 Gradual Introduction of a Distributed Resource Coordination and Control Platform

A distributed resource coordination and control platform uses equipment and information owned by stakeholders such as individuals and businesses, so it is important for stakeholder to reach a consensus on their participation in coordination control (building consensus). To build a consensus and promote a smooth transition to local communities, it is necessary to provide stakeholders with incremental value and create technologies and institutions to support this transition. For example, in the coordination of mobility and electric power, value can be provided in an incremental manner as shown in Figure 3-15.

The provision of electricity price information will allow individuals to obtain electricity more cheaply. Communities can receive support for the introduction of renewable energy by consuming and storing surplus electricity from renewable sources. Once a communication standards/security system has been set up and a grid code for device communication functions has been put in place, individuals will be able to obtain cheaper electricity by coordinating the power consumption of EVs and other devices based on real-time rates, allowing society to introduce a higher percentage of renewable energy. Furthermore, with a system that guarantees the controllability of equipment, and a

[27] Ministry of Economy, Trade and Industry, 2019: “Overview of the Cyber-Physical Security Measures Framework (CPSF)”. https://www.meti.go.jp/press/2019/04/20190418002/20190418002-3.pdf

grid code that defines communication and control functions on the equipment side, it will be possible for local communities to avoid overloading the distribution system, allowing individuals to gain the value of service revenues.

In this way, by developing technologies and establishing institutions that advance coordination while providing incremental value, it will be possible to create a virtuous cycle of "investment, effect, and reinvestment" in social change, and it will also be possible to provide value with a broader scope, such as ensuring the resilience of local communities.

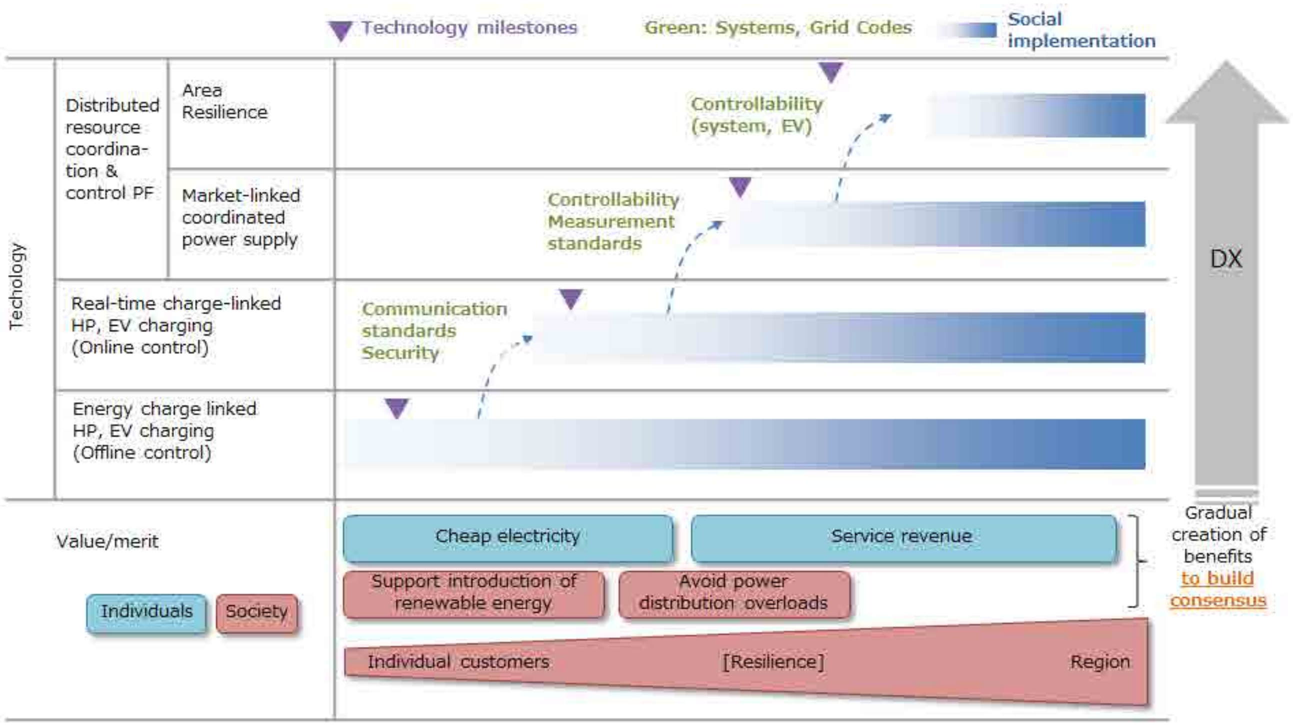


Figure 3-15: Incremental social implementation of a distributed resource coordination and control platform and the provision of value to individuals and communities

3.7 Summary

The contents of Chapter 3 can be summarized as follows.

- Considering the Japanese government's goal of achieving CN by 2050, the increasing severity of natural disasters as typified by Typhoons 15 and 19, the COVID-19 pandemic, and changes in people's lifestyles, we have examined the ideal state that local communities should aim for. With the participation of all members of local communities, it will be necessary to build energy data utilization systems that support smarter, more diverse energy sources and enable the transition to energy supply and demand structures that help these communities to achieve resilience faster.
- By casting back from 2050 and considering the change drivers that are currently active, it will be necessary to build an energy data utilization system that provides the adjusted value of EV recharging as an electric power

service by 2030, and to build systems for producing, distributing, and using hydrogen and new fuels by maximizing the use of surplus electricity from solar and wind power generation in 2050, by which time hydrogen and new fuels are expected to be in widespread use.

- The challenge is to build a supply chain that creates new value for local communities by using hydrogen and new fuels for various purposes. For example, one effective measure is to facilitate mutual coordination among the services using a distributed resource coordination and control platform (a type of data utilization platform).
- It is necessary to establish a secure and trustworthy energy data utilization system that includes data privacy protection and physical safeguards.
- To create a virtuous cycle of investment, benefits, and reinvestment related to social transition, and to smoothly obtain stakeholder consensus, it will be necessary to take a gradual approach to the development of technologies and the establishment/operation of systems.

Chapter 4: Framework Supporting Energy Bulk Power Systems

4.1 How Bulk Power Systems Should Implemented to Achieve Carbon Neutrality

In order to achieve carbon neutrality (CN) in line with the Green Growth Strategy,[28] the following issues need to be addressed in bulk power systems.

(1) Higher electricity demand: This is expected to increase by about 50% compared with the current level due to electrification

(2) Increased renewable energy capacity: Construction and grid interconnection work to support increases of offshore wind power from 45 GW (2040) to 80 GW (2050), onshore wind power 17 GW (2040) to 37 GW (2050), and solar power generation from 120 GW (2040) to 200 GW (2050)

(3) Securing adjusting capacity: Ensuring coordination capabilities to respond to fluctuations in the power generated from renewable energy

(4) Using large-scale power sources: Ensuring long-term power supply capacity and sufficient inertia to facilitate grid stabilization

(5) Using hydrogen: Making it possible to use hydrogen as a decarbonized fuel, and producing hydrogen to address the issues of uneven regional distribution of renewable energy, supply fluctuations, and dealing with surplus electricity

Compared to Europe and the United States, Japan has a number of potential problems: the lower stability limit of long-distance large power transmission due to the comb-shaped grid; the increased likelihood of frequency fluctuations due to supply-demand imbalances arising from fluctuations in renewable energy output in independent systems, and the need for long-term energy security due to the lack of grid interconnections with other countries. This means Japan will have to clear some large hurdles if it is to achieve carbon neutrality sooner than other countries. If possible, it should lead the way in technology development so that it can subsequently deploy practical solutions in other countries.

Table 4-1 summarizes the challenges and expected innovations in achieving the green growth strategy. It is necessary to establish decarbonization measures not only for electric bulk power systems but also for industry and transportation, as well as technologies for the production, distribution, and use of hydrogen and new fuels that will make this possible. Furthermore, to support electrification and hydrogen production, the renewable energy capacity

[28] Ministry of Economy, Trade and Industry, 2020: “Green Growth Strategy for Carbon Neutrality in 2050”. https://www.meti.go.jp/press/2020/12/20201225012/20201225012-1.pdf

in 2050 will need to be at least 3½ times greater than in 2030. Rebuilding power systems to accept these renewable energies is a major challenge.

Figure 4-1 shows the roadmap discussed in the backcast of the technology, institutional, and policy innovations necessary to achieve carbon neutrality by 2050. It is necessary to develop technologies, design systems, plan the construction of power sources and energy infrastructure considering the lead time for social implementation, and start strengthening the grid at an early stage.

With this transformation of the energy system, bulk power systems will play an important role in the overall optimization of "3E+S" (economic growth, energy security, environmental protection and safety) in society as a whole. The supply and demand of energy and the transfer of value will take place in multiple local communities, which will be connected by bulk power systems. In the 2030 cross-section, it will be important to strengthen the equipment and control operation aspects to respond to the increases availability of and demand for renewable energy in order to achieve carbon neutrality, while maximizing the capacity of bulk power systems currently in operation. At the same time, it is necessary to strengthen the resilience of renewable energy sources to short- and long-term output fluctuations caused by climate change and natural disasters.

Table 4-1: Challenges and expected innovations in green growth strategies

Class	No.	Item	Main issues	Innovations
Non-electric	1	Automobiles/ storage batteries	• EV price reduction and infrastructure development • Improved storage performance	• New car sales to be 100% electric by mid 2030s • Automotive battery packs for ¥10,000/kWh or less, and household storage battery systems for ¥70,000/kWh or less before 2030
	2	Hydrogen	• Power generation, transportation, low-hydrogen steelmaking • Transportation and manufacturing	• Hydrogen power generation turbines, low-hydrogen steelmaking, FC trucks (15 million units by 2050) • Supply cost of less than ¥20/Nm3 , introduction of 20 million tons by 2050
	3	Fuel ammonia	• Thermal mixed combustion • Supply	• Increase the ammonia co-firing rate and specialism of coal-fired power stations • Ammonia supply (100 million tons in 2050, price lower than natural gas by 2030)
Electric power	4	Increased renewable energy: Offshore wind	• Market creation • Infrastructure development	• Cost reduction (¥8–9/kWh by 2030–2035) • Improvement of the power grid to connect suitable wind power generation sites and power demand sites (DC transmission)
Carbon removal	5	Carbon recycling	• Separation of CO2 from exhaust • Reduction of collection cost	• Cost of separation and recovery (/CO2 t): Low pressure gas ≈¥2,000, high pressure gas ≈¥1,000 yen by 2030, DAC ¥2,000 by 2050

* Organized by Hitachi-UTokyo Lab according to the Green Growth Strategy DAC: Direct Air Capture

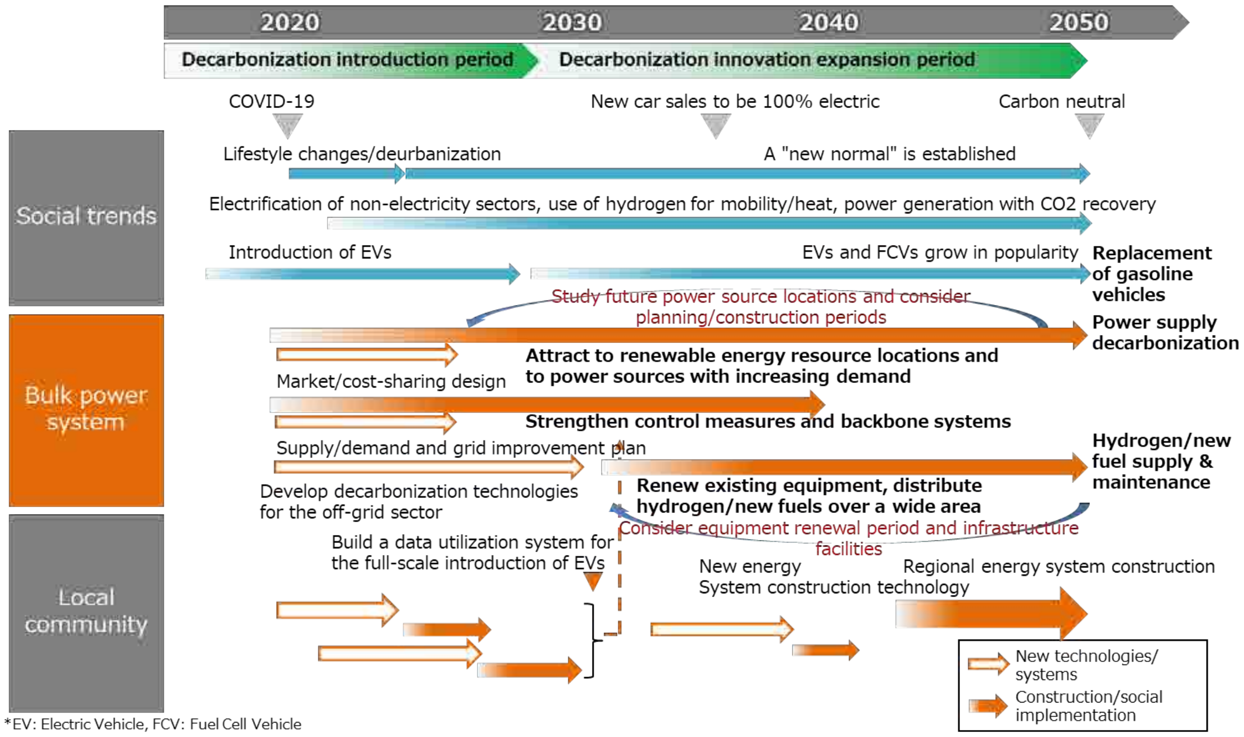


Figure 4-1: Transformation in bulk power systems with back-casting from 2050 and awareness of change drivers

Challenges that need to be overcome in order to make bulk power systems the main source of renewable energy include issues related to energy distribution and the balance of supply and demand, as shown in Fig. 4-2. In terms of energy distribution, the optimal locations for wind power generation are unevenly distributed in regions such as Hokkaido, Tohoku and Kyushu, and if wind farms are built where there are favorable wind conditions, then the transportation of energy to large consumption areas will be an issue. In terms of balancing supply and demand, for example, solar power plants will peak simultaneously during the daytime, which means it will be necessary to store power and shift demand to the daytime. To address these issues, we believe it is effective to strengthen Japan's transmission facilities and capacity, and to take measures to stimulate demand by, for example, locating data centers and hydrogen production facilities near renewable energy plants. We will also need to adjust demand in local communities and use power storage to provide adjusting capacity. Figures 4-3 and 4-4 illustrate the issues of energy distribution and supply-demand balance, respectively. As shown in Figure 4-3, it is envisaged that wind and solar power generation capacity equivalent to more than four times the maximum demand in Hokkaido, Tohoku, and Kyushu in will be introduced by 2050, making the uneven regional distribution of renewable energy an issue. In addition to eliminating the uneven regional distribution of power generation sites, it is necessary to guide the location of demand and rebuild bulk power systems. Also, as shown in Fig. 4-4, balancing supply and demand requires measures to be applied over a wide range of time scales (from seconds to years). At the system-wide level, consideration should be given not only to keeping the system balanced with regard to power outages arising caused by, for example, solar power output fluctuations, unpredictable changes, and long-term changes in the weather, but also to incorporating measures that provide resilience and energy security (e.g., power reserves).

In addition, there is a need to quantify and benchmark values (other than kWh output) that have hitherto been guaranteed by vertically integrated regional power companies, such as energy security and environmental sustainability. Following the separation of power transmission and distribution, the entire energy system will need to guarantee these values. During the transitional phase where various distributed energy resources are introduced alongside conventional power sources, a variety of values with characteristics that are highly variable in real time will gradually become necessary for purposes such as short-period supply and demand adjustments. A framework that gradually integrates these values into the operations of the core system through a trading market is desirable. In order to do so, it will be necessary to reflect these changes in the energy system based on analysis and evaluation of the energy system as a whole, not only from a technological perspective, but also with consideration given to systems and policies. For example, if the cost of energy supply from renewable energy sources (including subsidies such as FIT) becomes lower than the retail rate, we can anticipate that consumers who can afford to make the capital expenditure might develop an independent electricity system and leave the commercial grid, creating an imbalance whereby the remaining consumers would have to shoulder the growing cost to maintain the power grid. Local energy systems should not only evaluate the effectiveness of investment in terms of cost, but should also use multifaceted evaluation indicators to evaluate the technologies, systems, and policies to be introduced in terms of qualities such as environmental value, energy security, and long-term sustainability as a long-term project in consideration of fairness and welfare, as well as their environmental value and energy security.

Since Japan’s national territory is made up of large islands lined north to south, the country’s bulk power systems consist of regional power systems that serve large-demand areas and are linked to each other through AC and DC interconnections. This feature is also one of the reasons why there are concerns about frequency, voltage, and stability issues when renewable energy is deployed on a large scale. In addition, with the exception of inter-regional interconnection lines, Japan’s power distribution facilities have traditionally been formed so that grid congestion does not occur during normal times, and market and tariff systems have also been designed based on this premise. However, with the introduction of Japan’s Connect & Manage system, the formation of facilities that allow for grid congestion during normal times has begun even in local grids, including the trial introduction of non-firm connections that assume the possibility of grid congestion during normal times. To review the facility formation and tariff system, it is necessary to conduct a comprehensive study that includes the viewpoints of economic rationality and fairness among businesses. As a developed country, Japan should quickly solve these problems domestically and then contribute to the international community by deploying its technology and know-how across the world.

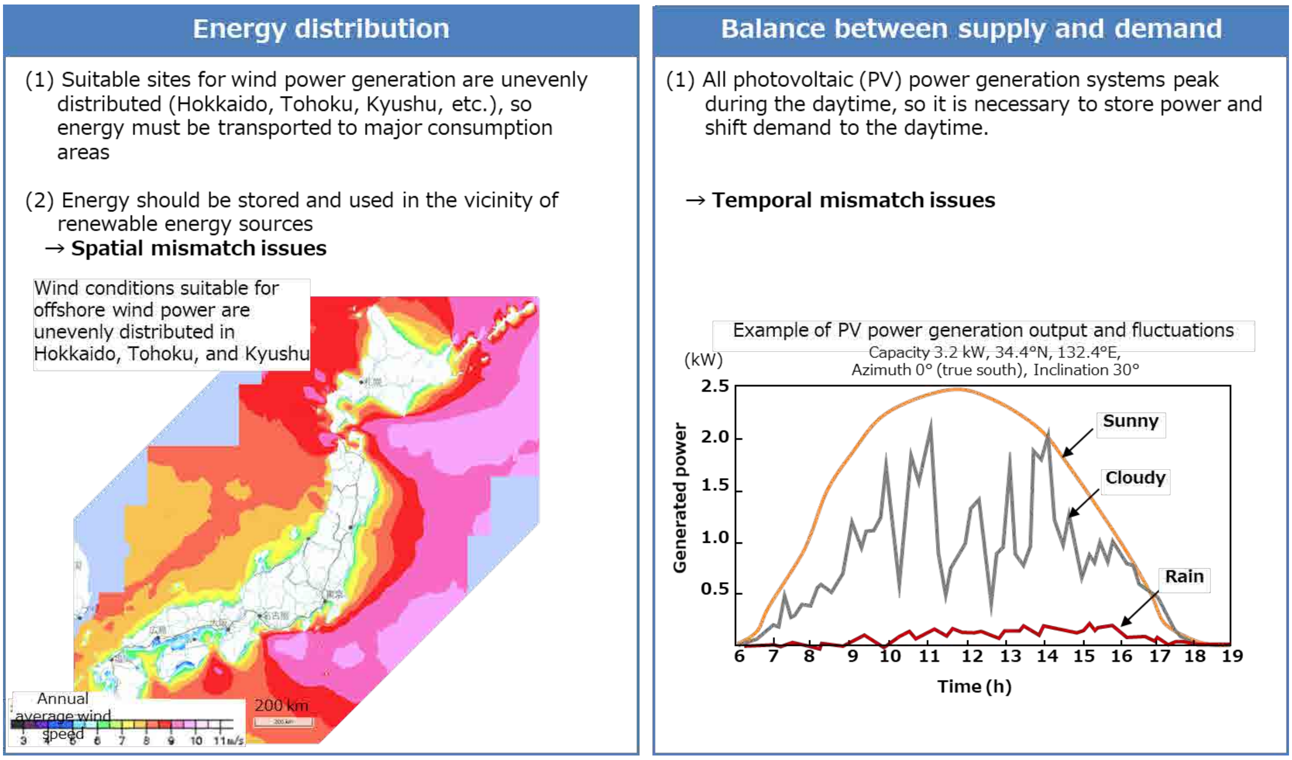


Fig. 4-2: CN implementation issues in the bulk power system[29]

[29] NEDO: “NeoWins (Offshore Wind Map)”. http://app10.infoc.nedo.go.jp/Nedo_Webgis/index.html.
Federation of Electric Power Companies of Japan, 2015: “Nuclear and Energy Drawing Collection 2015”.
https://www.fepc.or.jp/library/pamphlet/zumenshu/pdf/all.pdf

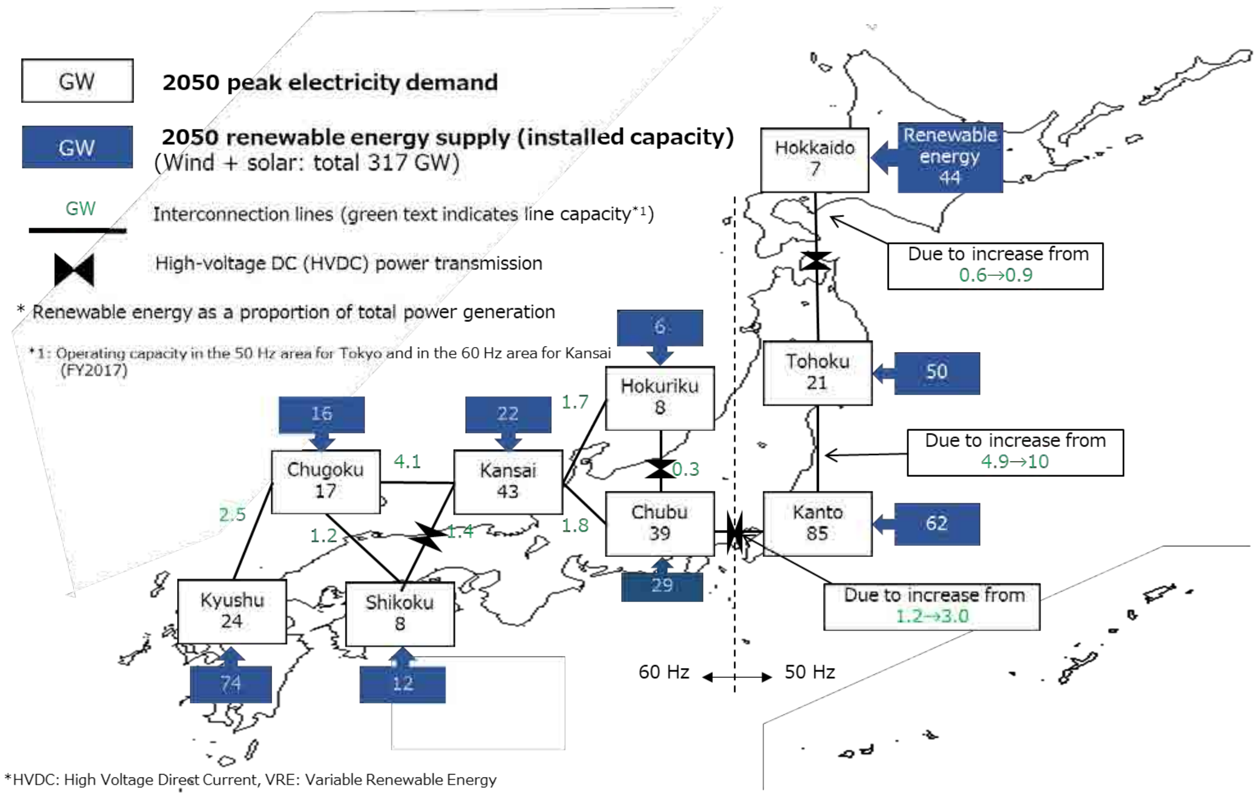


Fig. 4-3: Energy distribution issues

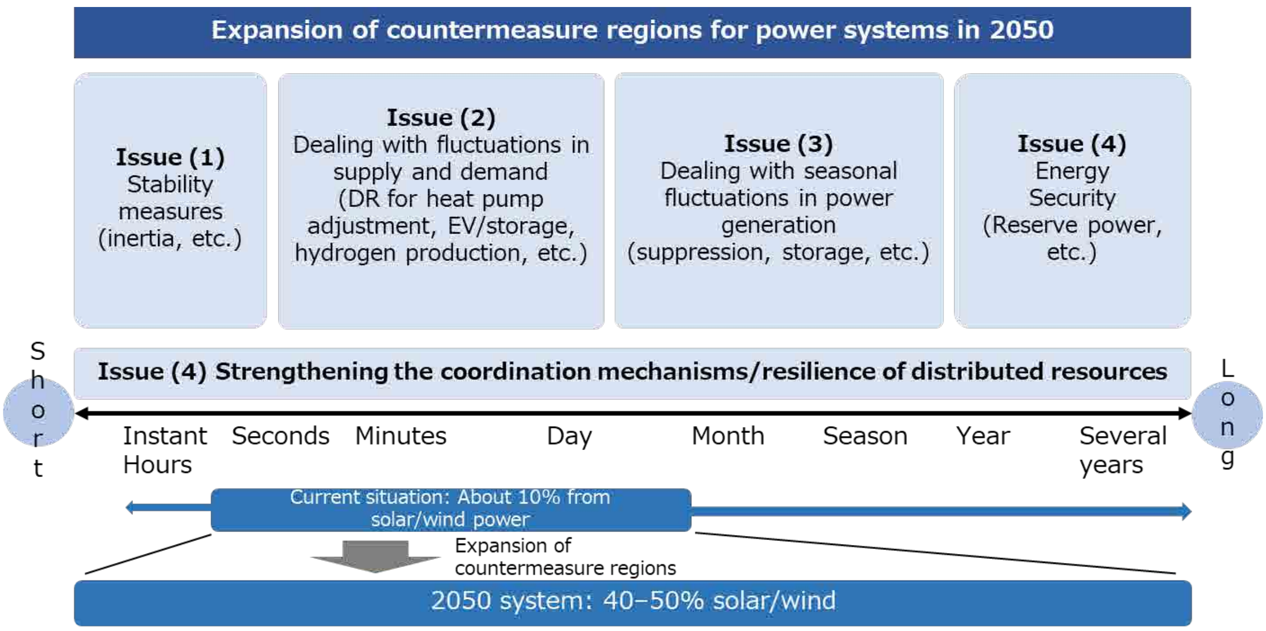


Fig. 4-4: Issues related to the balance between supply and demand

4.2 Evaluation Environment for Bulk Power Systems

(1) Evaluation platform

To achieve the expected roles for bulk power systems, we must prepare an environment where energy systems of the entire society can be analyzed and evaluated. The realization of desirable bulk power systems entails the quantitative assessment of various future challenges and cost-effectiveness for capital expenditure, and evaluating and sharing solutions from a range of perspectives.

For this purpose, industry, academia, and government should cooperate to build a platform where analysis tools and standard data can be developed and shared. To achieve a carbon-neutral society, it will be necessary to establish an open environment where it is possible to analyze and evaluate various future scenarios (e.g., EV interconnections and hydrogen conversion/storage) from diverse perspectives (including those of business operators and system designers) for mission-critical systems and local communities. It is also important to anticipate the costs of the various innovations shown in Table 4.1, and to proceed with the planning of measures that take returns on investment into account.

In the second version, examples of analytic tools for electricity systems included the electricity supply-demand analytical simulator and the wide-area (grid) stability simulator. As progress is made with the study of CN, these studies will be extended to enable the analysis of energy systems that include non-electric power, such as the production, distribution and utilization of hydrogen, as shown in the example of Fig. 4-5. Consideration will also be given to the effects of inter-regional electric and non-electric energy fusion and distribution, for example, between Tohoku and Tokyo. An example of this sort of evaluation calculation tool is shown in Fig. 4-6 (created by Hitachi-UTokyo Lab). The supply-demand balance and surplus electricity for each region can be obtained based on the annual demand for electricity and the results of renewable energy generation, whereby the required amount of controlled renewable energy output and the demand for hydrogen production facilities and HVDC[30] facilities can be roughly calculated.

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[30] High Voltage Direct Current

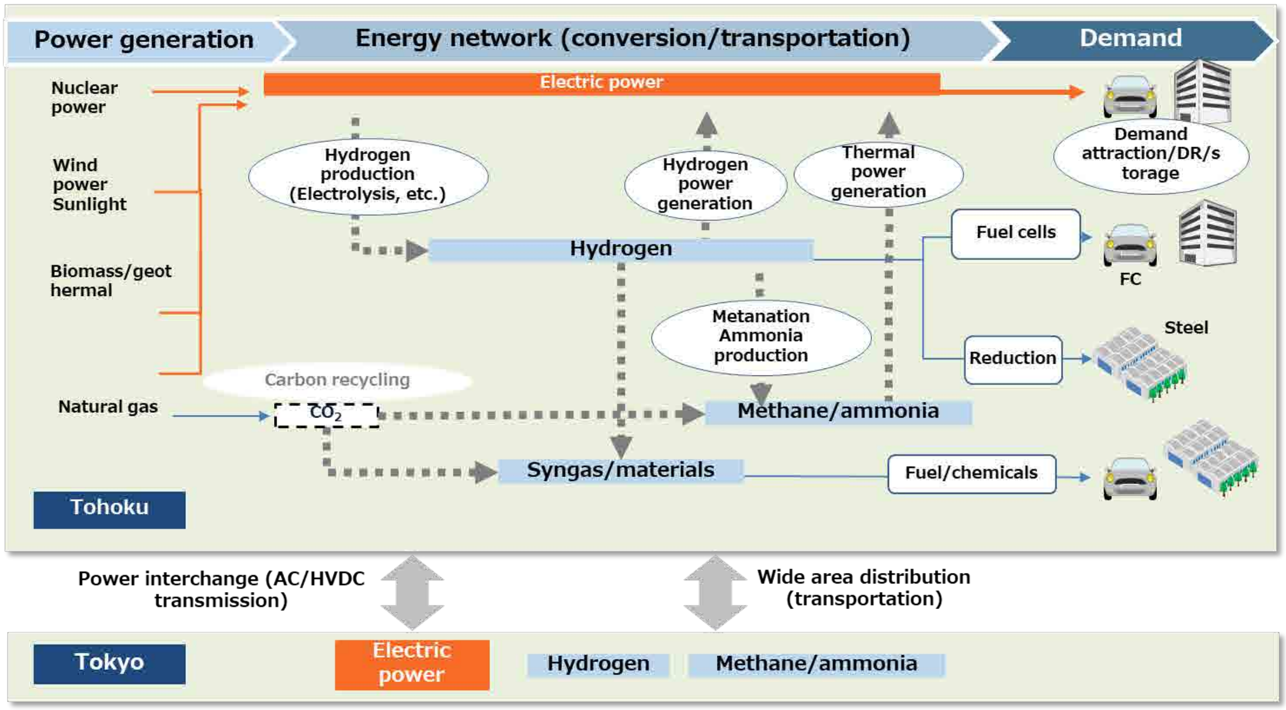


Fig. 4-5: Overview of the energy mix to be studied

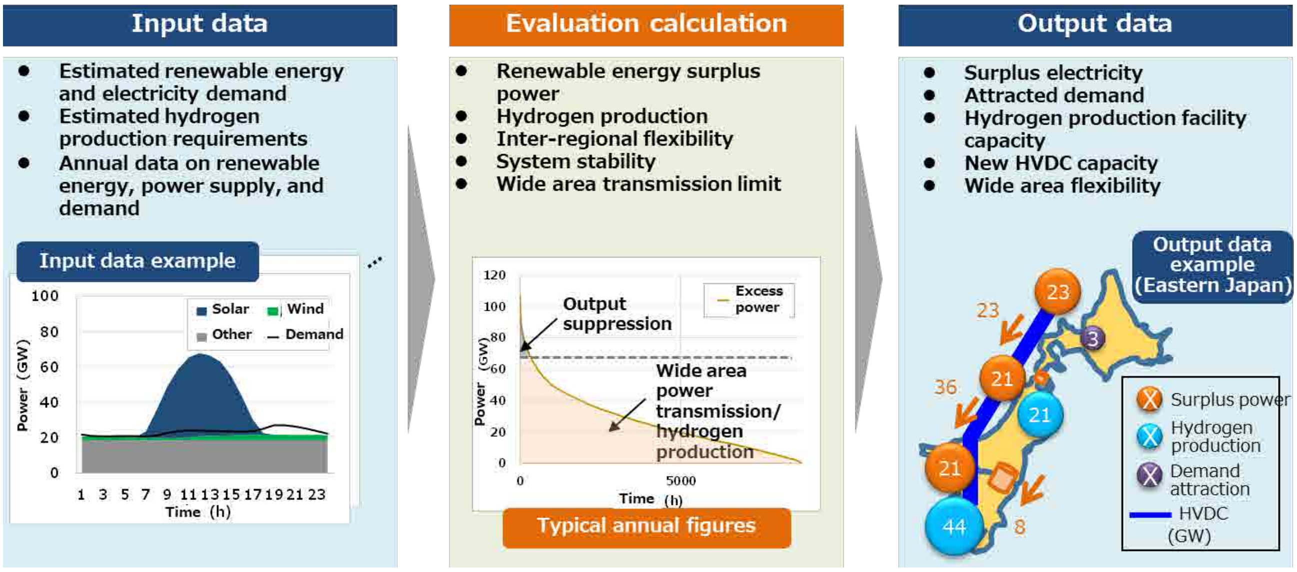


Fig. 4-6: Example of an energy system evaluation calculation (created by Hitachi-UTokyo Lab)

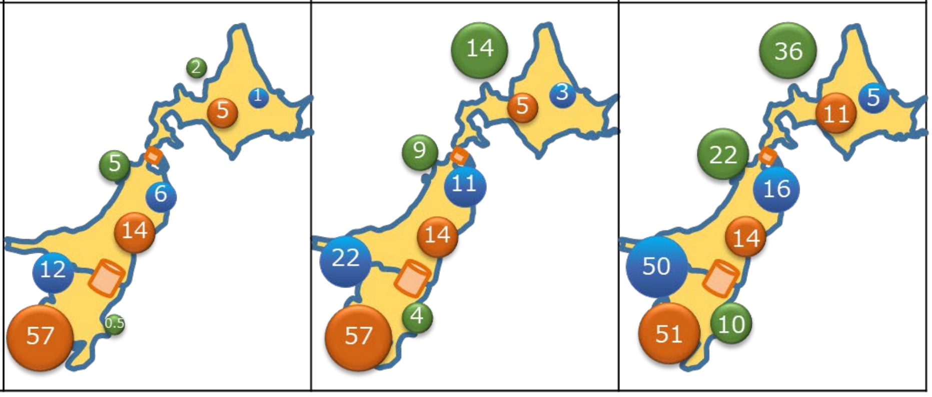
(2) Evaluation case study

Table 4-2 shows the issues and proposed measures for bulk power system in order to achieve carbon neutrality. The effects of these measures were estimated using the aforementioned evaluation platform, assuming the period from 2030 to 2050. This study was targeted at eastern Japan, where renewable energy sources such as wind power are expected to be introduced on a large scale. Figure 4-7 shows the conditions for estimating the demand for electricity and hydrogen, and the required amount of renewable energy facilities in the Hokkaido, Tohoku, and Kanto regions. The grid stabilization measures and the upper limit of the amount of power to be transferred between each region were determined by using the grid stabilization simulator shown in Version 2. The examination conditions are shown in Table 4-3. Each power company publishes information on the grid configuration, demand, and renewable energy generation, and the conditions were set with reference to this data.

Table 4-2: CN introduction issues in the bulk power system

No.	Possible issues	Countermeasures	Details (functions, effects)
1	**Destabilization of the power system** due to increased use of renewable energies such as wind and solar that lack inertia	• Pseudo-inertial control of renewable energy and use of rotary generators	• Implement pseudo-inertia by controlling renewable energy converters and synchronous phase-shifting of obsolete rotary machines
2	**Generation of surplus electricity** from renewable energy sources that cannot be supplied to the grid	• Use of hydrogen and new fuels	• Convert surplus electricity into hydrogen near renewable energy sources, and supply locally to FC trucks, etc. to alleviate uneven distribution • Reduction of electricity received through the use of hydrogen
3	**Limit the amount of power supplied** over a wide area of the power system	• Direct current (multi-terminal) power grid Expansion	• Use HVDC for long-distance high-power transmission of power such as offshore wind power to where it is needed
4	**Dissociation between energy demand centers and sites suitable for renewable energy**	• Location guidance	• Encourage renewable energy sources and users (hydrogen production, etc.) to choose locations that are close together
5	Increased power consumption due to rapid growth in information and communication equipment	• Reduce losses in semiconductor devices used in information and communication equipment	• Develop and use low-loss semiconductor technology to supersede SiC and GaN, and reduce the required amount of power generation

Period		2030	2040	2050
Prerequisites	Power demand	402.8 TWh (same as 2018)	×1.2*3) (Compared to 2030)	×1.5*1) (Compared to 2030)
	Hydrogen demand (×10,000 tons)	0*3)	100*3)	300*2)
* RE as a proportion of total power generation (%)		24	35	57
Distribution of VRE capacity and demand in Hokkaido, Tohoku and Tokyo PV Wind power Demand Interconnection line * Capacity (GW)				

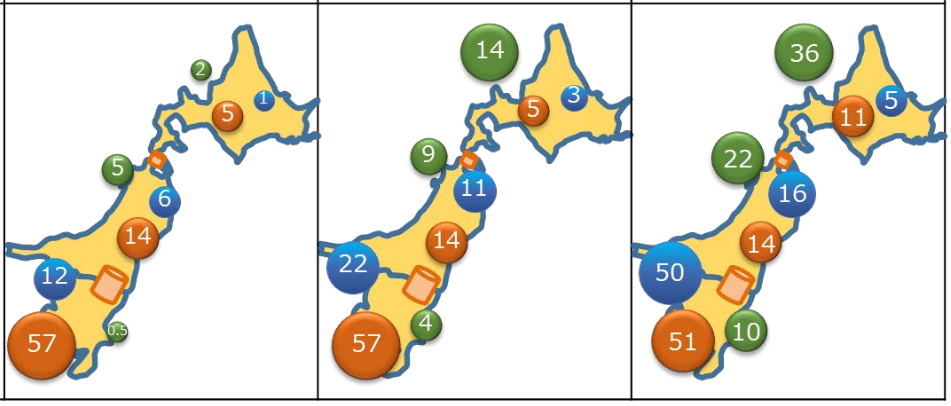


Assumptions: *1) Ministry of Economy, Trade and Industry, "Green Growth Strategy for Carbon Neutralization in 2050," December 25, 2020. *2) Assuming that East Japan is half of the whole country based on 1). *3) Estimated based on *1)

Fig. 4-7: Conditions for studying electricity demand and estimating the amount of renewable energy to be introduced in each region of eastern Japan

Table 4-3: Main calculation conditions used in the simulation

#	Item	Premises/constraints
1	**Power generation**	• Generator constants/AVR/PSS/governor should comply with IEEJ and ETRA models
2	**Demand**	• Set the demand for each year by proportionally multiplying the **2018 published value (8,760 hours)**
3	**VRE**	• FRT: Simulated by grid-connected regulations • Renewable energy generation: Calculated from the **actual output in 2018** and the projected output for future years [1][2].
4	**Systems**	• Assume the year 2030 (OCCTO plan), 275 kV and above will be **modeled from public data**, while 66 kV and below will be reduced.
5	**Pumping**	• All 13.2 GW used for VRE measures
6	**Breakdown**	• Assume 6LG-O on major trunk lines

Period		**2030**	**2040**	**2050**
Prerequisites	**Power demand**	**402.8 TWh (same as 2018)**	**×1.2*3) (Compared to 2030)**	**×1.5*1) (Compared to 2030)**
	Hydrogen demand (×10,000 tons)	**0*3)**	**100*3)**	**300*2)**
*** RE as a proportion of total power generation (%)**		**24**	**35**	**57**
Distribution of VRE capacity and demand in Hokkaido, Tohoku and Tokyo				

Assumptions: *1) Kanto demand will be attracted to Hokkaido, *2) Manufacturing efficiency will be 1.3 times higher than in 2020

* Estimated conditions during periods of large surplus electricity from renewable energy sources (suppression of output corresponding to approximately 5% of annual renewable energy generation)

Fig. 4-8: Energy composition in East Japan for each fiscal year, and the results of countermeasure estimation

Under these conditions, hydrogen production, demand attraction, and grid measures were called for to satisfy the supply-demand balance throughout the year. An example of the results is shown in Fig. 4-8. Based on the results of these calculations, the following points can be raised.

(a) In 2030: Excess power generation in Hokkaido and Tohoku will have to be addressed through demand response measures and water pumping. By implementing measures that are currently planned, including strengthening the AC power grid and improving the demand response, it should be possible to meet the 24% renewable energy ratio stated in the basic energy plan. Based on a grid analysis conducted separately, measures to eliminate overloads and perform voltage stabilization and synchronization in the power transmission and distribution network will still be necessary in the 2030 cross section.

(b) In 2040: The amount of introduced renewable energy will exceed the capacity of the existing AC system, which means HVDC facilities and hydrogen production facilities will be required. It is also important to produce hydrogen in the vicinity of renewable energy sources and to supply and store it in FCVs and FC trucks.

(c) In 2050: To produce 3 million tons of hydrogen in East Japan with renewable electricity, it will be necessary to introduce more than 3½ times the amount of renewable energy introduced in 2030, resulting in more surplus electricity in each region. On the other hand, further expansion of HVDC facilities will be needed to transmit power to the vicinity of the hydrogen production facilities.

Thus, during 2040–2050, in addition to building renewable energy systems, it will also be necessary to construct transmission facilities such as HVDC facilities to deliver offshore wind power to the bulk power system. A practical way of responding to the increase in renewable energy without having to massively increase the amount of wide-area power sharing in the bulk power system is to place hydrogen production equipment so that hydrogen can be produced and stored in the vicinity of renewable energy sources. Separate grid stabilization measures, such as reinforcement of regional grids and strengthening of grid voltage control, will also be required to cope with the increase in solar power generation and onshore wind power as well as the increase in demand associated with electrification and motorization. We will study what measures to take by performing grid analysis based on concrete assumptions about the configuration of renewable energy production and demand.

4.3 Collaboration with Local Communities

To reap the benefits of demand-side resources throughout the energy system of the future, it will be necessary to incorporate and implement new control technologies that digitally connect the bulk power system with local communities, and to prepare market trading systems and systemic designs. For example, we will develop new control technologies such as virtual power plants (VPPs), demand response systems, and smart inverters attached to renewable energy. By allowing local communities to share the responsibility for controlling the supply and demand adjustment functions that are currently handled by thermal and pumped storage power generation systems, it will be possible to maximize the cost effectiveness of the community systems while making effective use of the potential of existing facilities. To achieve this, it is important to develop an IT infrastructure that links large quantities of community facilities, and to establish rules for control schemes or incentives that maximize their effectiveness. Mutual cooperation could be implemented through a system whereby the “quality” of electricity seen in the entire power system (for example, a kW or ΔkW value), is demanded either directly (by a control command) or indirectly (by incentives, etc.) from the local community, thereby leveraging the local community’s coordinating capabilities. As a reference case, we describe the demonstration project conducted by NEDO on Niijima Island (Tokyo), entitled “Mitigation Technologies on Output Fluctuations of Renewable Energy Generations in Power Grid.” The project simulates a model power system in Niijima based on the anticipated domestic ratio of renewable energy in 2030, while studying various challenges and proposing solutions. For example, the project develops and evaluates a grid system by predicting and controlling the output of renewable energy and coordinating with existing power sources and storage batteries. The system is operated with an optimal combination of control technologies, including measures against excess power, mitigation of fluctuations, and planned power generation. The project is also studying resource aggregation and balancing groups, which are expected to be used in future power system reforms, and is demonstrating the cooperative operation of multiple distributed control systems (Fig. 4-9).

Period		2030	2040	2050
Power generation	VRE (GW)	17	41	96
	Surplus power (GW)	8	20	65
Counter-measures Example	Hydrogen production (GW)	0	20	65*2)
	Attracting demand (GW)*1)	0	0	3
	New HVDC (GW)	0	12	36

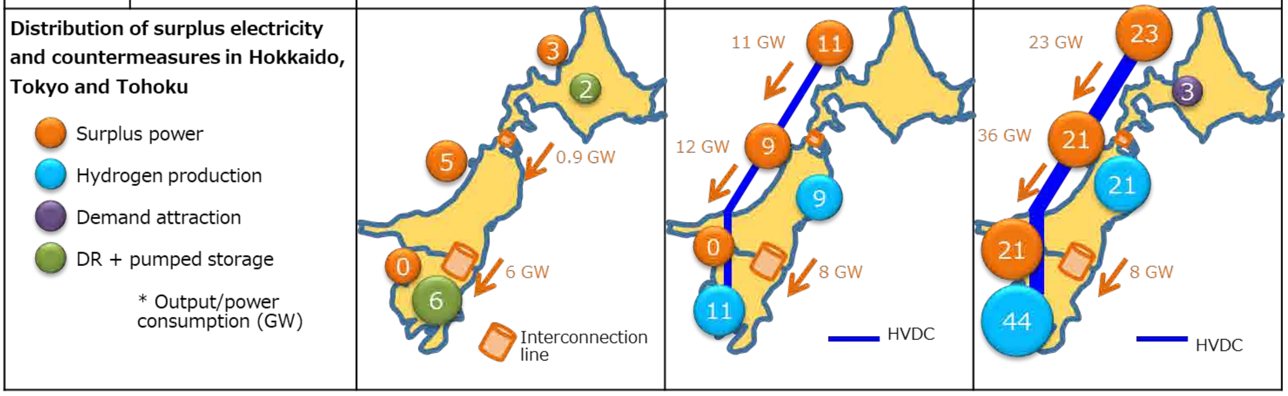


Fig. 4-9: Demonstration of a model electricity system based on the expected energy mix for 2030[31]

31 NEDO, 2019: Research and Evaluation Committee, Subcommittee on Research and Development of Technology for Power System Output Fluctuation (post audit) https://www.nedo.go.jp/introducing/iinkai/ZZBF_100392.html

4.4 Summary

- We need to build an energy network that facilitates CN by addressing the uneven distribution of electric and non-electric energy, and plans for power supply/demand allocation, hydrogen utilization/distribution facilities and the development of decarbonization technology for the steel and chemical industries should be immediately advanced to the 2030 target.
- To facilitate the study of energy value chains, the formation of consensus among stakeholders, and the planning of institutional policies, we must develop an integrated operation/evaluation platform that enables quantitative evaluation, and enable the sharing of data in order to achieve this.

Chapter 5: Socio-Economic Issues and Structural Transformations to Address Challenges and Reforms Towards Achieving Carbon Neutrality

The first and second editions of this proposal suggested "performance-driven" policies that support the transformation of core systems in the electric power system, and the introduction of institutions and policies that enable the construction of diverse, mutually complementary systems in local communities. Achieving carbon neutrality (CN) will require not only a performance-driven approach in power systems, but also the expansion of performance-driven policies that use economic methods to promote behavioral change and solutions to solve the economic challenges of introducing decarbonization technologies for both supply and demand.

In this chapter, we identify the economic challenges of introducing decarbonization technologies to realize CN, and we propose an economic approach to encourage technological innovation with minimum social cost in order to develop institutions and policies to solve these economic challenges. We also discuss the establishment of market principles in the energy system and the need for an international framework to realize CN.

5.1 Fleshing Out the Future Vision of Energy Systems

Figure 5-1 summarizes how local communities and bulk power systems should be configured to achieve CN as discussed in the previous chapters. In the study of local communities, the challenge is to encourage consumers to choose decarbonizing technologies. The study of bulk power systems identified issues arising from regional disparities in the distribution of energy. Performance-driven policies provide mechanisms for smoothly addressing these social and economic issues in the future of the energy system, and for achieving maximum efficiency at minimal cost to society as a whole.

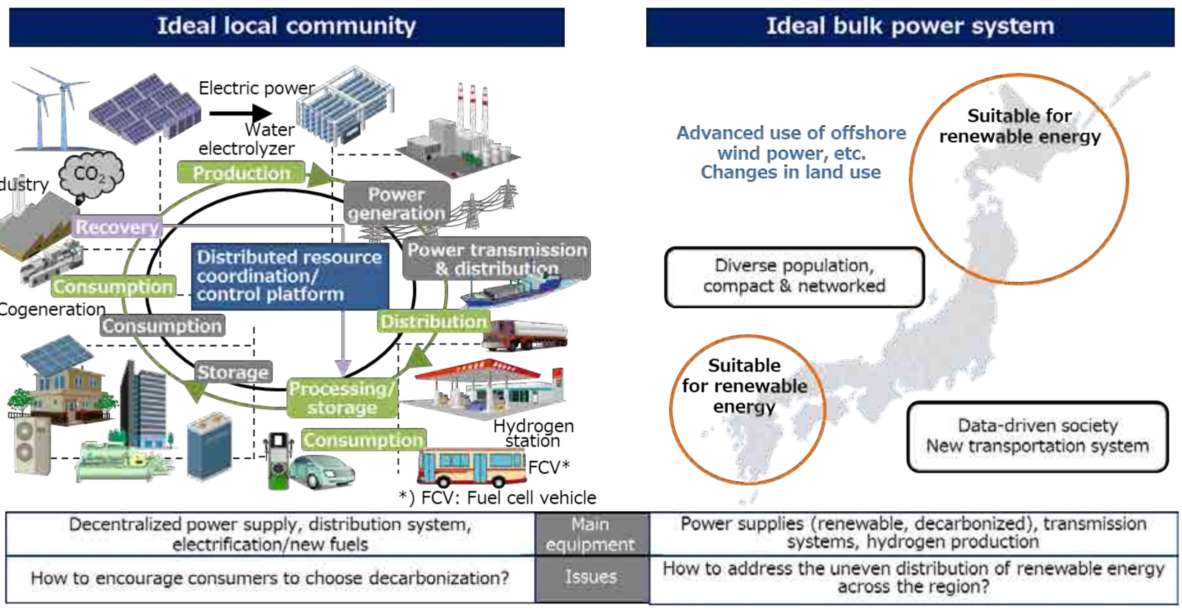


Fig. 5-1: Socioeconomic issues in the energy systems of the future

5.2 Performance-driven Policies to Facilitate the Resolution of Energy System Issues

(1) Extension of performance-driven policies

Performance-driven policies encourage continuous improvement by quantitatively evaluating the progress towards policy goals by means of simulators and indicators, and by implementing policy planning with the involvement of stakeholders. Quantitative evaluation considers not only the economic benefits achieved through innovation, but also diverse values such as energy security and sustainable development goals (SDGs).

In the second version of the proposal, the goal of performance-driven policies was stated as achieving an optimal combination of economic growth, energy security, environmental protection and safety ("3E+S") in bulk power systems for the whole of society, and recommendations were made for setting 3E+S goals, establishing a common platform, and establishing cost-sharing rules. CN cannot be achieved by decarbonizing the electric power sector alone; it must apply to the entire energy system, including bulk power systems and local communities. The topic of planning discussions must be expanded from the establishment of cost-sharing rules with an emphasis on fairness (as discussed in Version 2 for the purpose of expanding the diffusion of renewable energy and improving the grid), to economic methods for encouraging technological innovation with an emphasis on behavioral change to motivate the introduction of decarbonization technologies throughout the entire energy system—i.e., the inclusion of consumer voices in coordination mechanisms (Fig. 5-2).

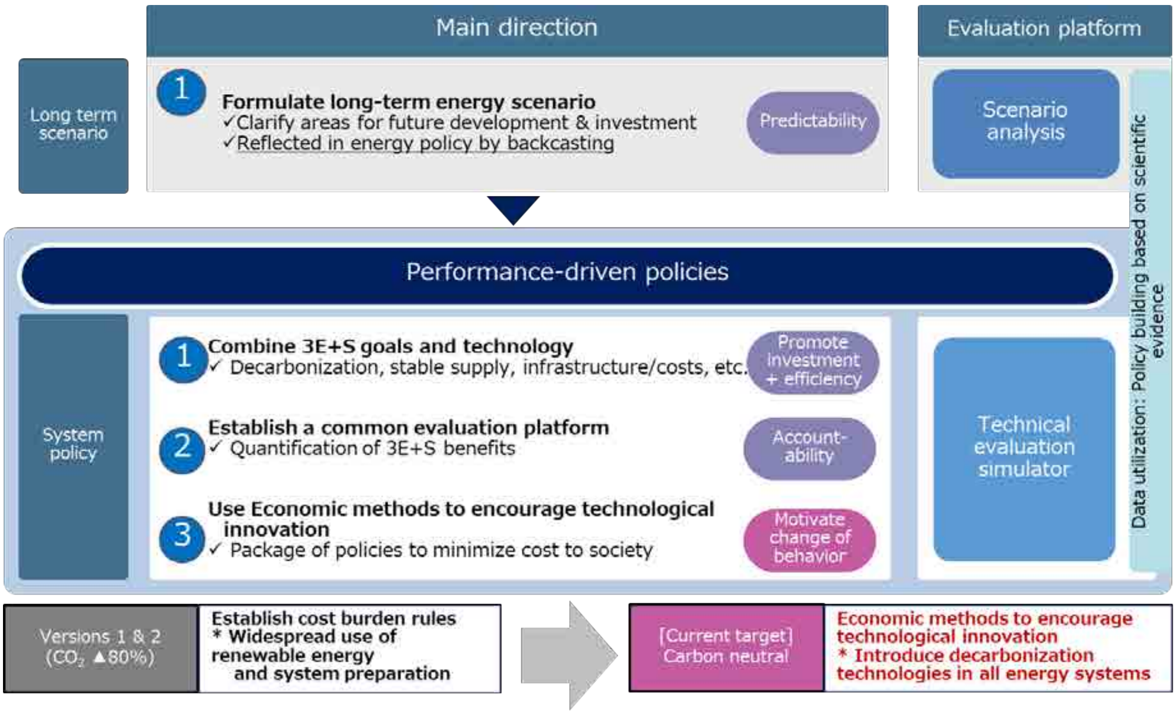


Fig. 5-2: Socioeconomic issues in the future of energy systems

To implement performance-driven policies, it will be necessary to develop long-term energy scenarios, as shown in Figure 5-3. This proposal examines the long-term energy vision from the perspective of socio-technical scenarios, which will be discussed later in Chapter 6, and discusses what should be kept in mind in performance-driven policies in light of important changes occurring in society and in the public and private sectors. The policy formation process will be established within a framework of evidence-based policymaking (EBPM [32]) to analyze the socio-environmental and energy systems, and to study the institutions and strategies needed to achieve CN and 3E+S.

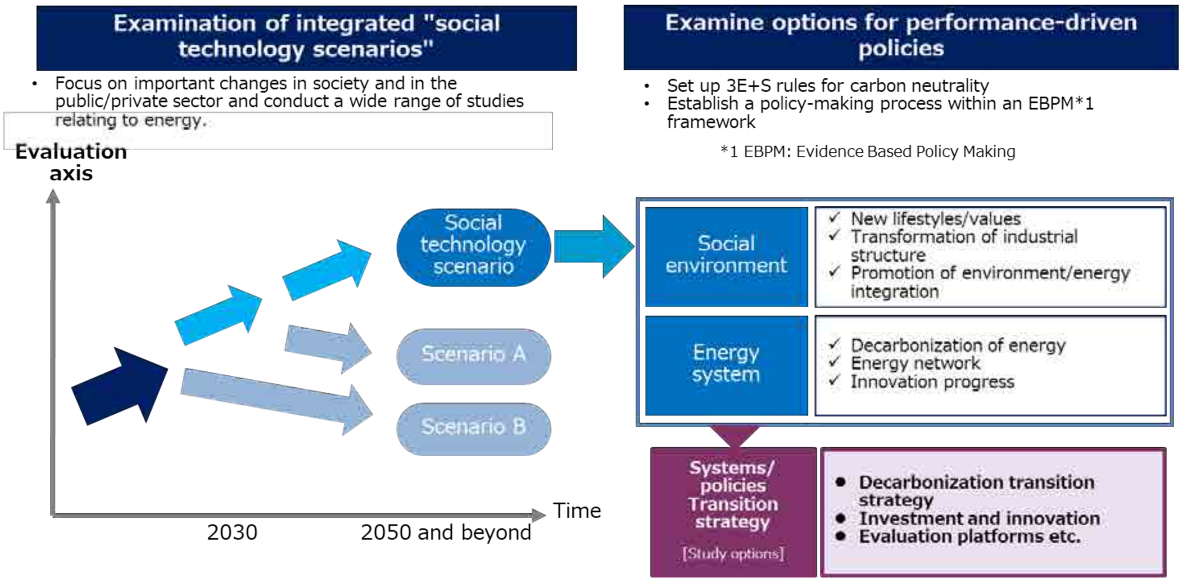


Fig. 5-3: Socioeconomic issues in the future of energy systems

(2) Combining technology options to optimize the overall energy system, including bulk power systems and local communities

To examine strategies and policies for achieving CN, it is necessary to consider the overall energy system for providing 3E+S optimization (see Fig. 5-4). Among energy systems, solar and wind power are attracting attention as established technologies in the field of power generation, and new developments are expected in the field of carbon-free power sources, such as the restarting of existing nuclear power plants, the development of small-scale reactors (SMRs), carbon capture, utilization and storage (CCUS) systems for thermal power stations, and power generation methods using hydrogen and ammonia as fuels. On the consumer side, new lifestyles are becoming possible through the electrification of everyday devices, as well as electric vehicles and hydrogen fuel cell vehicles. It is important to consider the combination of these technologies in order to develop a strategy for the realization of CN.

[32] Evidence Based Policy Making: An approach centered on the use of objective evidence, such as statistics and simulations, to develop and test hypotheses for policy options, and to formulate policies through open discussion among stakeholders.

In energy systems, there are many ways in which technology choices can be combined. We will quantify the economic and environmental benefits of technologies in the process of developing energy strategies and policies, and we will implement evidence-based policymaking (EBPM) in the policy evaluation process.

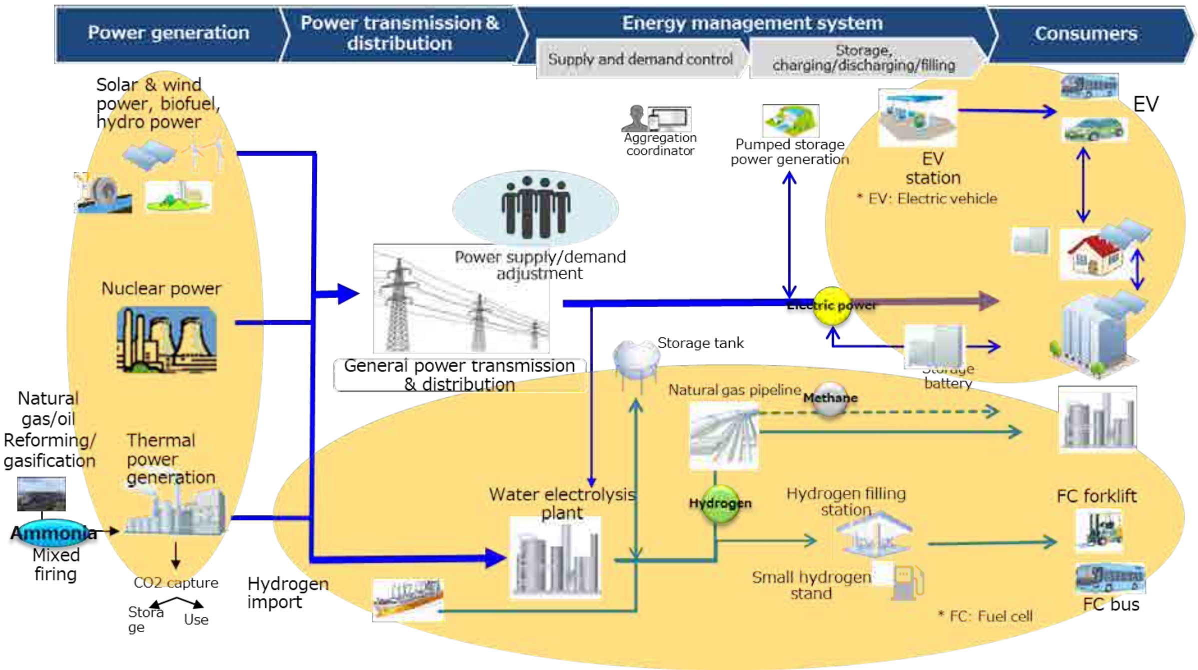


Fig. 5-4: Technology options for the entire energy system

(3) Establishment of evidence-based policymaking (EBPM)[33]

EBPM is a process that achieves smooth policy formation by extracting policy issues, visualizing multiple proposals, comparing and evaluating them, and building a policy-making cycle in the course of policy evaluation. As an example of EBPM, Fig. 5-5 shows a study of measures that have been proposed to expand the introduction of renewable energy and eliminate regional disparities in Hokkaido and eastern Japan. In this figure, STEP3 (Evaluation of policy proposals) is important for quantifying and discussing policy proposals, and for establishing an integrated evaluation platform.

[33] Ohashi, H. (ed.), 2020: The Economics of EBPM: Evidence-Based Policy Making, University of Tokyo Press.

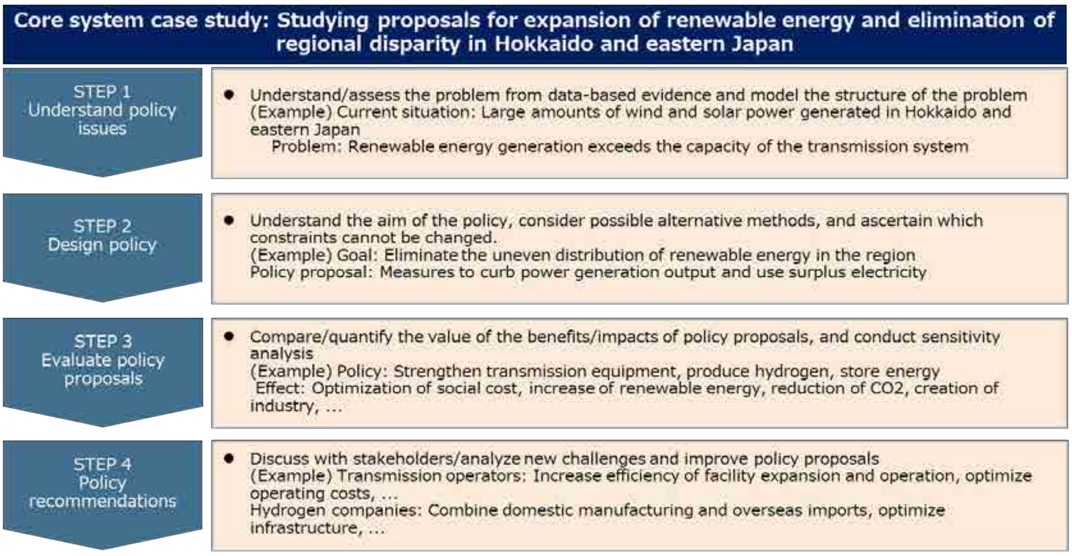


Fig. 5-5: EBPM steps and examples of core system studies

(4) Establishment of an integrated evaluation platform

It is important that the policy proposal evaluation platform is capable of being verified by a third party. For the integrated evaluation platform, Version 2 used a technology selection model to quantitatively evaluate future energy systems, and Hitachi-UTokyo Lab will continue to study a price model based on supply costs, evaluation of technology with a grid simulator, and an economic model to evaluate the macroeconomic impact of energy systems (Fig. 5-6).

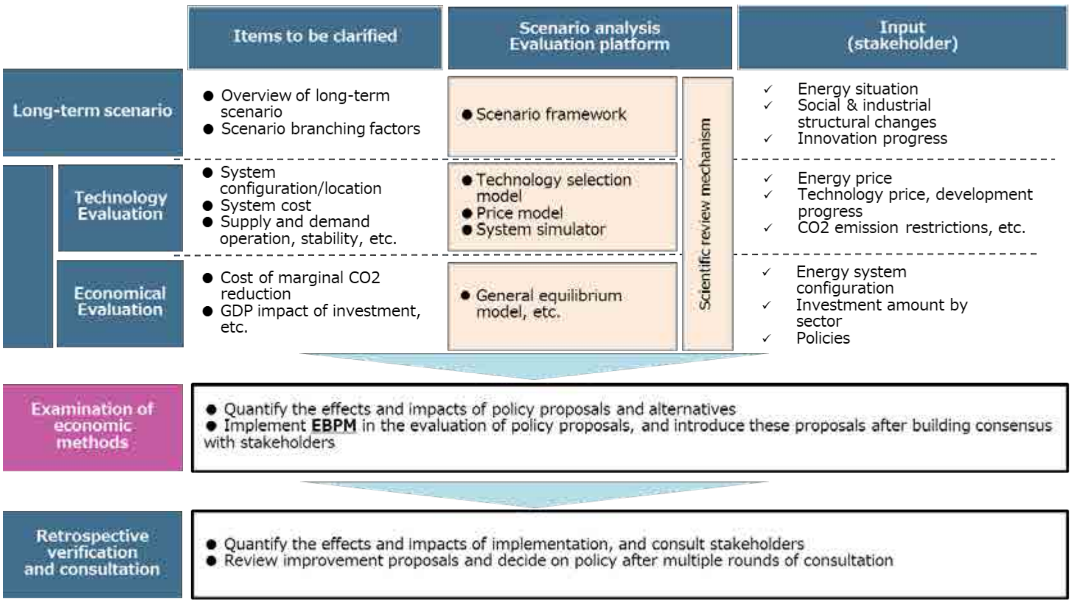


Fig. 5-6: Using an integrated assessment platform for long-term energy scenario studies and institutional/policy implementation processes

5.3 Market Principles and the Establishment of 3E+S in Energy Systems

Since the beginning of the 2000s, numerous changes have taken place in the domestic and international energy markets. In Japan, the Great East Japan Earthquake (March 2011) caused major changes in the direction of energy planning, and in 2013, a policy was adopted to reform Japan's electricity systems. In the international community, the price of crude oil started to rise in 2004, reaching $147/barrel in July 2008. In the mid-2010s, the quantity of shale gas extracted in the US increased significantly, and by 2020, energy prices had plummeted due to COVID-19 pandemic and other factors. In this section, we examine how the 3E+S and CN initiatives can take root as the energy market is formed.

(1) Issues in electricity system reform as seen from price fluctuations in the Japan Electric Power Exchange (JEPX)

The electricity system reforms that were drawn up in April 2013[34] led to a break in April 2020, and with the legal separation of the power generation and retail functions, each sector began to maximize its own profits. Between December 2020 and January 2021, the JEPX price soared to a maximum of ¥251.0/kWh (Fig. 5-7). This was due to increased demand for electricity caused by factors including a period of very cold weather, sluggish growth of solar power generation due to snowfall, and fuel constraints. A more remote cause was Japan's electricity system reform, whereby the vertical integration model came to an end, which made the coordination of information among power generation and retail companies weaker and more difficult. With the formation of the electricity market, efforts are required to establish the market principles that the electricity system reform aimed to achieve, which should combine a stable supply with the overall optimization based on 3E+S.

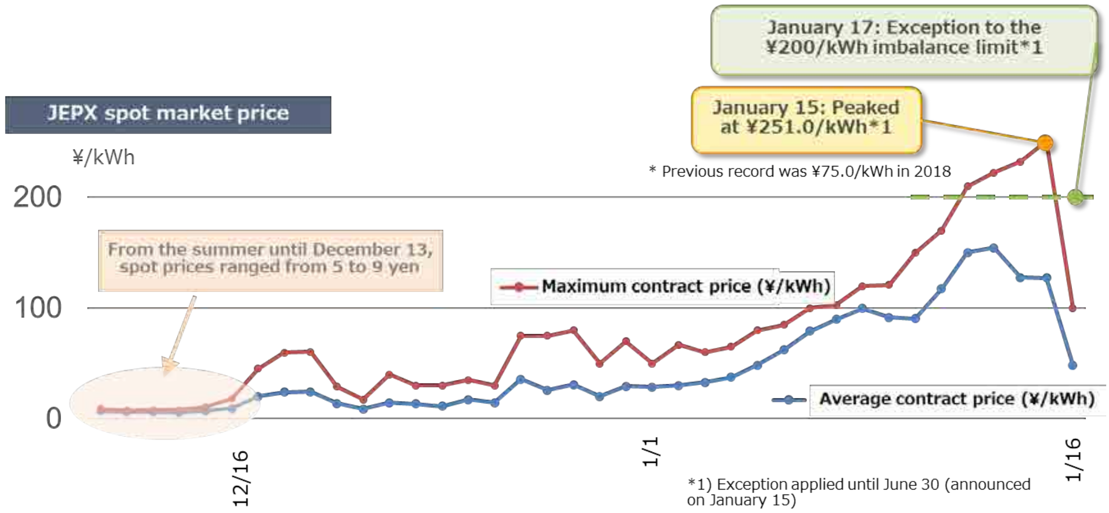


Fig. 5-7: JEPX Spot Price (Dec. 2020 to Jan. 16, 2021)[35]

[34] In the "Reform Policy for Electricity System Reform" approved by the Cabinet on April 2, 2013, it was indicated that (1) wide-area grid operation should be expanded, (2) retail and power generation should be fully liberalized, and (3) neutrality of the transmission and distribution sectors should be further ensured through legal separation.

[35] Compiled from data provided by the Japan Electric Power Exchange (JEPX)

(2) Decarbonization innovation arising from the energy market

An OECD study found a strong correlation between prices and decarbonization innovation in energy markets. In graph on the left side of Fig. 5-8, the correlation between the price of crude oil and the level of R&D activity in decarbonization innovation is evaluated in terms of the number of patents related to low-carbon technology and energy saving. On the other hand, as can be seen from the change in the price of crude oil due to the outbreak of Coronavirus on the right of Fig. 5-8, a global pandemic can cause a downward trend in energy demand and prices as economic activity stagnates. The decarbonization innovations that will shape energy systems of the future should minimize the impact on investment due to the coronavirus pandemic and the stagnation of economic activity. We expect national initiatives will promote these efforts, and are hopeful that the above investments will lead to revitalization of energy markets.

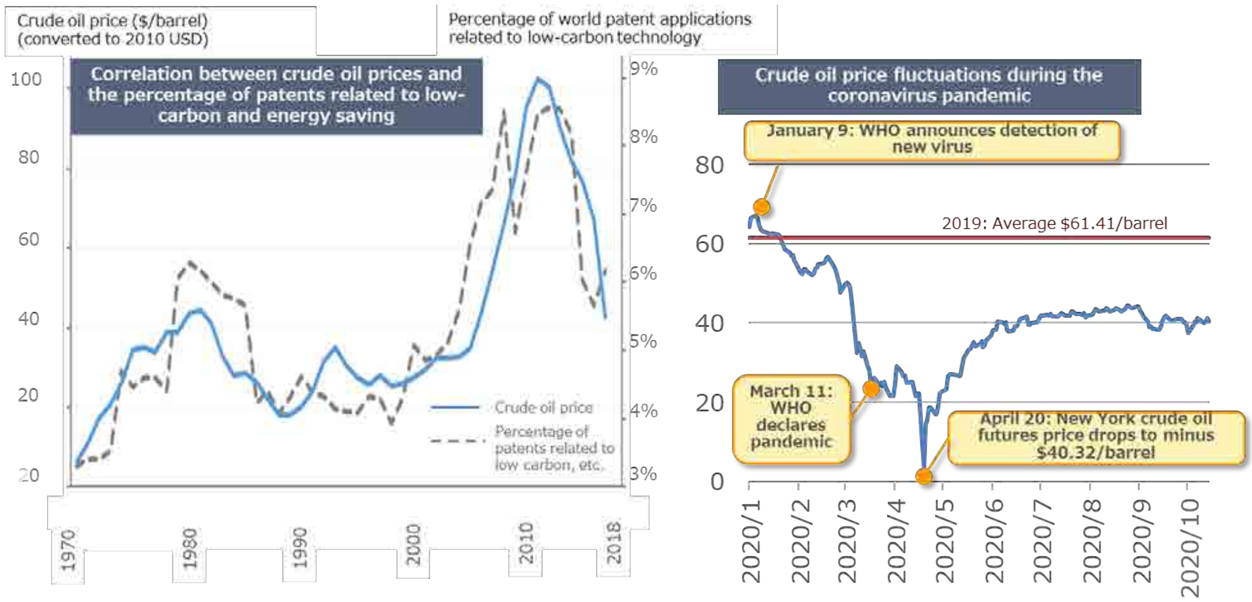


Fig. 5-8: Correlation between crude oil prices and technological innovation, and the effect of coronavirus on crude oil price trends[36]

5.4 International Framework for Achieving Carbon Neutrality

CN policies are currently being promoted in Japan, Europe and China. In the midst of drastic changes in the world situation, one issue that needs to be discussed is the role that Japan should play in the realization of CN in the international community. In addition to adjusting domestic and international borders, it is also important to participate

[36] Source: (left) OECD (COVID-19 and the low-carbon transition), (right) World Bank (Commodity Markets)

in rule-making to maintain our national interests. It is also important to review domestic systems in line with international rulemaking.

As shown in Figure 5-9, explicit carbon pricing (CP)[37] measures such as emissions trading systems (ETS) and carbon taxes (CT) have been considered and introduced in many countries around the world. In Japan, we have been working on implicit CP measures such as energy taxes and feed-in tariff (FIT) systems, and we have collaborated with the Tokyo Metropolitan Government and Saitama Prefecture to introduce coordinated measures.[38] However, as shown in Table 5-1, Japan's efforts have not been "visualized" as CP, the total amount of CP is recognized to be low compared with other countries, and a proper evaluation has not been obtained. Discussions have begun on the nature of CP, but it is also important for Japan's policy to include a visualization of CP that should be communicated to the international community.

Efforts must be made to reduce CO_2 emissions not only in Japan but throughout the world. CO_2 emissions are currently calculated on the upstream side of products and services, but this has not changed consumer behavior and has not led to global decarbonization efforts. To encourage consumers to choose decarbonization, we believe that it is also necessary to have a system whereby the CO_2 emissions of commodities can be visualized on the consumer side.

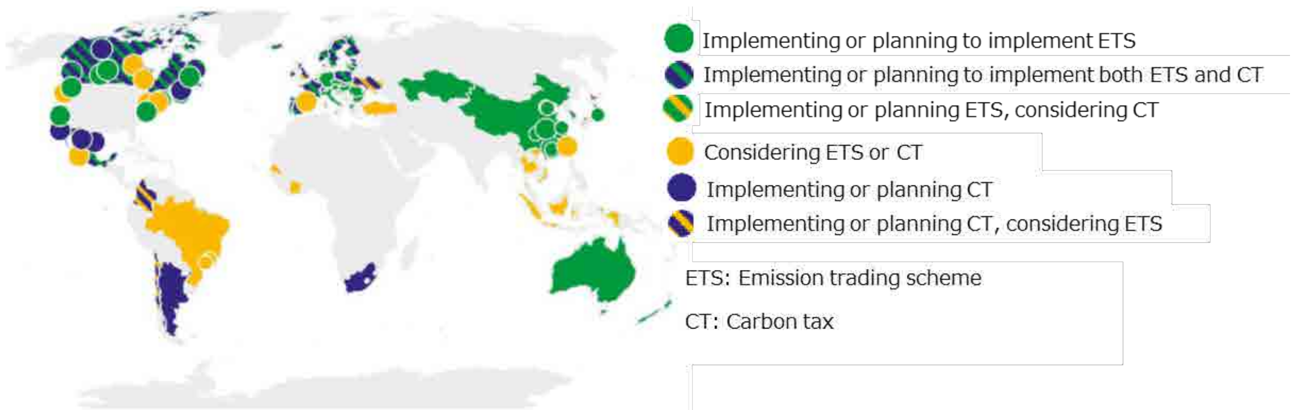


Fig. 5-9: Planning and introduction of carbon pricing in each country and region[39]

[37] Carbon pricing is a system that aims to reduce CO2 emissions by raising carbon-based energy prices and lowering demand. While it is expected to promote investment in carbon reduction, there are concerns about the relocation of production bases, etc. to other countries.
[38] The Tokyo metropolitan government introduced emissions trading (cap-and-trade system) in 2010, and Tokyo and Saitama prefectures began working together in 2011.
[39] World Bank (Carbon Pricing Dashboard)

Table 5-1: Comparison of total explicit carbon pricing in 37 countries/regions[40]

Units: (USD/t- CO_2)

Total amount of ETS+CT	Name of country/region (total amount of emission trading + carbon tax) *ETS: emissions trading system, CT: carbon tax
30+	Sweden (119), Finland (68), Norway (53), France (49), Iceland (30)
20+	British Columbia/Canada (28), Ireland (28), Denmark (26), Portugal (26) Alberta/Canada (21), New Zealand (20)
10+	Switzerland (19), California/USA (17), Quebec/Canada (17), South Korea (17), Beijing, China (13), Australia (10), Latvia (10), Zacatecas, Mexico (10)
5+	Massachusetts/USA (8), Baja California/Mexico (7), South Africa (7), **Tokyo/Japan (6), Saitama/Japan (6)**, Northeastern US states (RGGI) (6), Shanghai/China (6), Chile(5)
3+	Guangdong Province/China (4), Hubei Province/China (4), Fujian Province/China (4), Tianjin City/China (4), Chungking City/China (4), **Japan (3)**, Shenzhen City/China (3)
<3	Mexico (2), Kazakhstan (1), Poland (0.07)

*Excludes implicit prices, such as energy taxes and FIT systems (because they are treated differently in each country, making uniform comparison difficult)[41]

5.5 Summary

- We have proposed the development of performance-driven policies to solve the socioeconomic challenges of the energy system. It is important to establish a policy planning and evaluation process based on EBPM, and to establish a platform for integrated evaluation of long-term scenarios and technology options, and the impact of technology choices on society and the environment.
- We have proposed the establishment of market principles and 3E+S optimization and CN realization efforts in energy systems. The surge in JEPX prices should be taken as an opportunity to re-examine whether the overall optimization of 3E+S (which is based on the premise of providing a stable supply) has been achieved. On the other hand, decarbonization innovation is also highly linked to energy market prices, and it is preferable to promote initiatives based on market mechanisms.
- We have discussed Japan's CN policy and how it relates to the international community. It is important to strengthen efforts aimed at reflecting national interests in international rulemaking, including border adjustments,

[40] Based on data from Word Bank (Carbon Pricing Dashboard), updated November 2020.

[41] A running carbon price (USD/t-CO_2) has not been produced since OECD Carbon Effective 2016 (produced from data as of April 2012). In the proposal (Version 3), we compared explicit CPs using the latest data from public institutions.

and to optimize domestic systems in line with trends in international rulemaking. Furthermore, to encourage consumers to make decarbonization choices, there is a need for a mechanism that makes the CO_2 emissions of products and services more apparent to consumers.

Chapter 6: The Necessity of Multidimensional "Socio-technical Scenarios" Depicting Changes in Society

Fundamental changes—or, "transitions"—in society to achieve the unprecedented goal of carbon neutrality (CN) require efforts to drastically transform all areas. To effect such structural transformations steadily and with sufficient speed, it is important that diverse actors present the challenges that must be overcome from their perspectives and identify the paths that must be taken to achieve the goals. "Transition scenarios," which present integrated transformations in various areas of society, point the way forward for the efforts to be taken. This chapter discusses the requirements of transition scenarios and the perspectives uncovered so far through discussions with stakeholders.

6.1 Multidimensionality of Transitions

The goal of CN cannot be achieved simply by improving power and grid technologies or by exerting various efforts in the industrial sector. Fundamental changes in energy systems will require major transformations of people's lives, society, and economic activities.

A general theory of social and technological long-term structural transformations, or transitions, is the multi-level perspective (MLP), presented by Frank Geels of Manchester University.[42] MLP presents the an analytic framework for understanding the processes by which existing systems in areas such as energy, mobility, agriculture, or housing (socio-technical systems or regimes), unable to maintain their conditions due to a crisis such as climate change or the collapse of biodiversity, drastically transition to other systems.

In this framework, an existing system is characterized by its path dependency on existing conditions. An existing system is "locked in" in the following ways: (1) economically, by vested interests and existing infrastructure's capabilities and low costs, (2) socially, by existing common cognitive frameworks and users' lifestyles, and (3) politically, by vested interests and policy networks.

Against the background of these conditions, new radical innovations (niche innovations) arise from the periphery of existing systems. New products form micro-niches. While in the beginning inferior in capability to existing products, the new products surpass them over time. On the other hand, these changes are considered to arise under the macro "landscape" level. Some changes, such as climate change and demographic change, occur over time. Others, such as wars, recessions, and pandemics, occur rapidly.

MLP explains the process by which systems undergo transitions as result of intra-conflicts at multiple levels.

[42] The seminal paper is Frank W. Geels, 2002. "Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case study," *Research Policy* 31, 1257–1274.

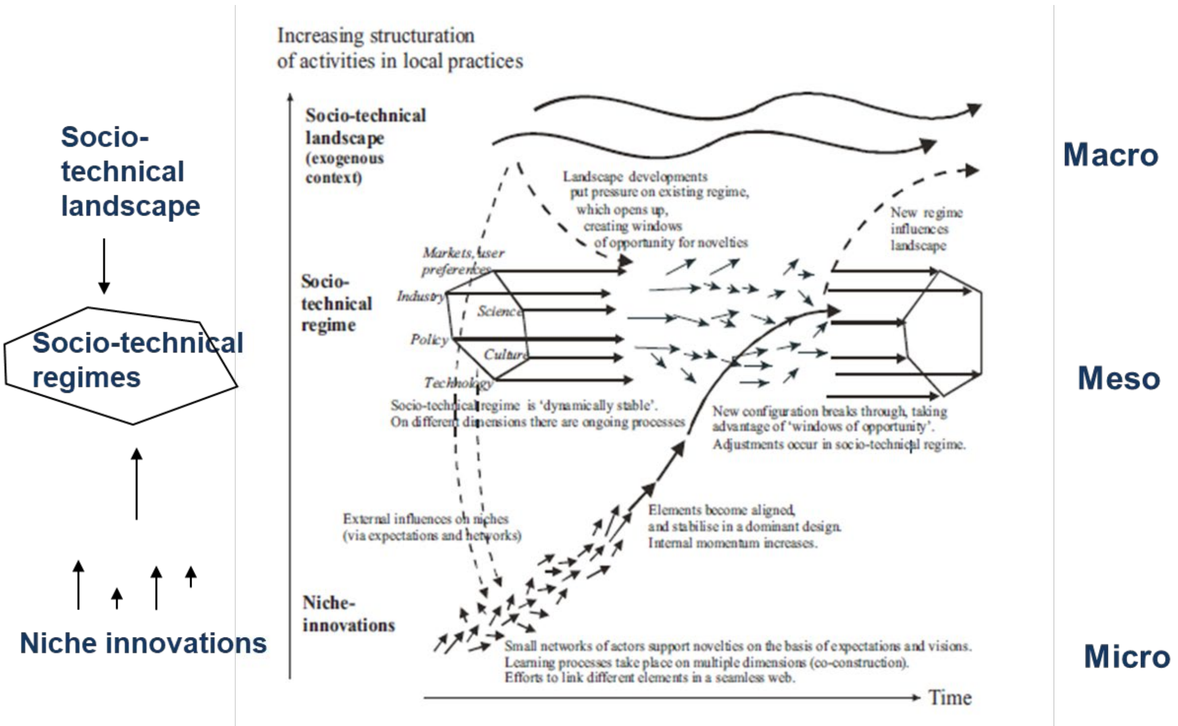


Fig. 2. Multi-level perspective on transitions.

Figure 6-1 Overview of multi-level perspective on transitions[43]

What is critical here is that under MLP, a system is understood to be composed not simply of technologies but also of mutually supporting industries, policies, cultures, sciences, markets, and users' preferences. This is the reason MLP calls a system a socio-technical system (system in which society and technology are interconnected) or regime.

The transition of an energy system from an existing system to the next system must then be seen as not only involving the technological dimension but as comprising complex structural transformations with various dimensions. With rapid progress in international action on climate change, old systems are facing pressure to change in political, economic, and social dimensions.

The International Renewable Energy Agency (IRENA) thus states, "The power and energy systems are embedded into the wider socioeconomic system, which in turn is embedded into the earth and its climate" and "In order to avoid dysfunctional outcomes, a holistic policy framework is needed to frame and support the transition."[44]

Therefore, to realize a radical transition to new energy systems and bring about a CN society, we must consider not only electrical but a wide range of energy systems, and not only accurately present technological conditions that makes transition possible, but also shed light on various factors while identifying the economic, political, and social transformations that should occur.[45]

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[43] Frank W. Geels. 2011. "The multi-level perspective on sustainability transition: Responses to seven criticisms." Environmental Innovation and Societal Transition 1, p. 28 (Adapted from Frank W. Geels, 2002. "Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case study," Research Policy 31, 1257–1274.)

[44] International Renewable Energy Agency. 2019. *Global Energy Transformation: A Roadmap to 2050.* (https://www.irena.org/-/media/Files /IRENA/Agency/Publication/2019/Apr/IRENA_Global_Energy_Transformation_2019.pdf)

[45] In the economic dimension, an important question is what kinds of relationships emerge between existing actors and new entrants and bring about change. In the political dimension, questions include how new structures formed in the relationships between local governments, NGOs, and new entrepreneurs can supersede old structures that support decision-making. In the social dimension, it will be necessary to study how new options can be supported by raising awareness of climate change and by public opinion. In the real world, each dimension has existing actors, interests, and obstacles. It is thus necessary to discover the form of transforming

6.2 The Importance of Integrated Socio-technical Scenarios

To investigate scenarios that contribute to large-scale and rapid transition of energy systems, with the long-term goal of realizing CN, Hitachi-UTokyo Lab is studying diverse energy-related scenarios developed inside and outside Japan. An explanation of a portion of our approach is given in Appendix 3.

In general, the term “scenario” refers to a depiction of multiple events and conditions that can occur in a future that has not yet happened. A scenario presents these multiple events and conditions in temporal continuity,[46] but can take one of various forms depending on the approach in considering the relationship between current reality and the desired future.

The most important point in perspectives for realizing a decarbonized society is to recognize the gaps found between pathways produced by “forecasting,” which proceeds from current trends, and pathways produced by “backcasting,” which proceeds from the achievement of goals, and to consider how a trajectory to eliminate these gaps can be achieved in the early stages.

The Hitachi-UTokyo Lab seeks to depict social transitions centered on the transformation of energy systems to achieve CN in Japan while sharing a fundamental approach to “transition scenarios,” which present structural transformations to realize a sustainable society. The transitions describe the transformation of socio-technical systems discussed above, and can be called “socio-technical scenarios.”

To achieve this goal, the Hitachi-UTokyo Lab has made foundational the following approach:

(I) Backtracking from 2050: After considering social conditions in present-day 2020, we envision the future of 2050 as well as an intermediate stage (2030/40), and consider social transformations along a temporal axis to connect present-day conditions to the envisioned future.

(II) Changes in social, public, and private sectors: To understand long-term, complex social transformations, our method pays simultaneous attention to three sectors—(1) social, (2) public, and (3) private—and focuses on important conditions and changes occurring in these sectors. In this way we seek to simultaneously grasp the perspectives of actors in the social sector, which is the primary sphere of activity of citizens, NGOs, and universities; the public sector, the sphere of activity of the national and local governments and public agencies; and the private sector, the sphere of activity of companies and investors. We will then be able to more accurately understand changes in which the roles of citizens, governments, and companies and climate action, public policies, and economic activities are intertwined in a complex manner.

(III) Integrated scenarios and transition strategies: Taking an integrated perspective on changes occurring in the above areas, we will investigate socio-technical scenarios related to long-term transition and transition strategies that contribute to a proposal for the near future.

Our approach is depicted in Figure 6-2.

existing structures under these complex dynamics.

[46] The method of depicting future “scenarios” was originally developed in the field of “scenario planning.” Organizations such as corporations and government agencies used it to gain strategic foresight while dealing with medium- to long-term uncertainties. The method gained prominence due to the influence of Herman Kahn, a futurist known for his consulting work for the U.S. Air Force after World War II, in particular. Its adoption by Royal Dutch Shell in the early 1970s, which helped the company to weather the 1973 oil crisis and come out ahead of its competitors, made the method well-known.

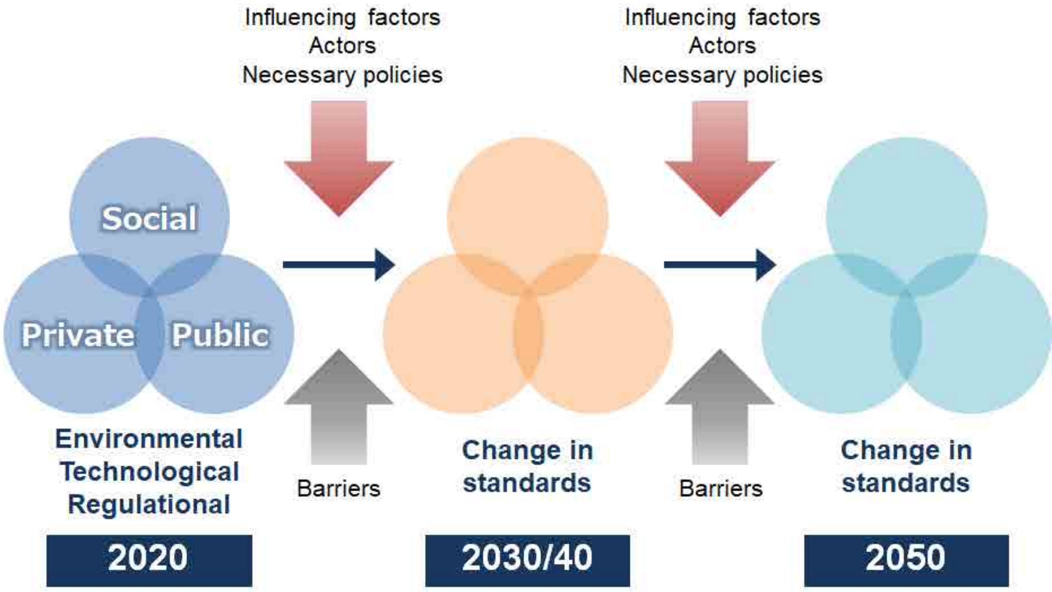

Figure 6-2 Relationships in the study of socio-technical scenarios

Referencing contemporary research on transition scenarios (see Appendix 3), the Hitachi-UTokyo Lab will conduct original analysis on (II) "Changes in social, public, and private sectors" in particular. Here we focus on (a) structures, (b) actors, and (c) decision-making in the transition process.

(a) Structures: To realize CN in Japan, current structures require fundamental transformation. We must analyze the current structures and the shapes of sustainable structures after transformation. As we have already argued, the transition to sustainability faces obstacles such as conservative behavior and stagnation due to interconnections of existing ties of interest and path dependency on conventional behavioral patterns that support these interconnections. To avoid "lock-in," resulting in failure of transition, we must present the structures of existing energy systems in all their forms and the vision of the future that should be realized, based on the analysis of relationships between elements.
(b) Actors: We will analyze how various actors in society can cooperate and compete to achieve decarbonation. An actor is an agent of action. Actors include power companies and manufacturing companies in the private sector, climate action groups and socially responsible investment networks in the social sector, and governmental organizations in the public sector. When considering transitions in the context of Japan, two dynamics have particular significance.[47] The first is the development of new entrants in niches and the changes they bring to the socio-technical system itself, while having disruptive impact on other actors.[48] The second dynamic is the pathway of incorporation of new technologies and business models by existing actors to change the socio-technical system itself.

[47] Geels, Frank W., et al. "The enactment of socio-technical transition pathways: a reformulated typology and a comparative multi-level analysis of the German and UK low-carbon electricity transitions (1990–2014)." *Research Policy* 45.4 (2016): 896-913; Geels, F. W., Andy McMeekin, and Benjamin Pfluger. "Socio-technical scenarios as a methodological tool to explore social and political feasibility in low-carbon transitions: Bridging computer models and the multi-level perspective in UK electricity generation (2010–2050)." *Technological Forecasting and Social Change* 151 (2020): 119258.

[48] For example, disruptive innovations such as those observed in the digital industry may occur in the energy industry. The "prosumerization" of consumers as well as actions by environmental NGOs are expected to bring about new impact.

This dynamic is also critical.[49] In this way, focusing on the how a new system is formed as new and old actors change together is a critical step in accurately understanding changes in industries involved in the creation of a CN society.

(c) Decision-making: The challenge of making renewable energy, which is closely tied to diverse natural environments and local economic development, the main source of energy, cannot proceed without the resolve of local governments and citizens in Japan's regions. Meanwhile, global climate politics and developments in decarbonation are moving the Japanese government and companies to rapidly shift their directions. As responses to climate change accelerate, it is critical to conduct meticulous study of the tensions arising between the central and local governments, citizens and local governments, producers and consumers, and of the desired consensus formation and collaboration between stakeholders.

6.3 Hitachi-UTokyo Lab's Transition Scenario Development Process

(1) Expert interviews

To investigate structures, actors, and decision-making as described above, the Hitachi-UTokyo Lab has begun expert interviews by selecting informants from social, private, and public sectors with experience and knowledge related to transitions to new societies. From discussions with these stakeholders (see Appendix 3 Figure III-4), we aim to obtain information and key perspectives necessary for investigating scenarios.

By February 2021, we will have interviewed many experts including members of international NGOs involved in business valuation, researchers of environmental policies and urban digital platforms, renewable energy providers, electric vehicle manufacturers, petrochemical company operators, venture capitalists, high-ranking officials in the Japanese government, and field staff members of international energy organizations.

Various issues in the social, private, and public sectors were raised in the expert interviews (Figure 6-3). We found that each issue was not independent of others but instead should be perceived as intimately connected. For example, working toward the goal of global decarbonation, related to efforts to address the climate crisis, is deeply related to the following questions: What kinds of renewable energy generation and transmission is suitable for Japan's rich topography? What consensus can people in local communities form about the installation of renewable energy facilities? How can these facilities create frameworks for sustainable local economic development?

In this way, we must pay attention to the complex and dynamic interconnections between elements: between the global and local, technology and society, and local development and the environment. To realize a CN society by 2050, we must find a path for transition under these complex conditions.

[49] For example, there are cases of the global tide of ESG investments causing major energy companies to significantly develop their renewable energy businesses. This movement will also impact companies such as heavy electric machinery and automobile manufacturers.

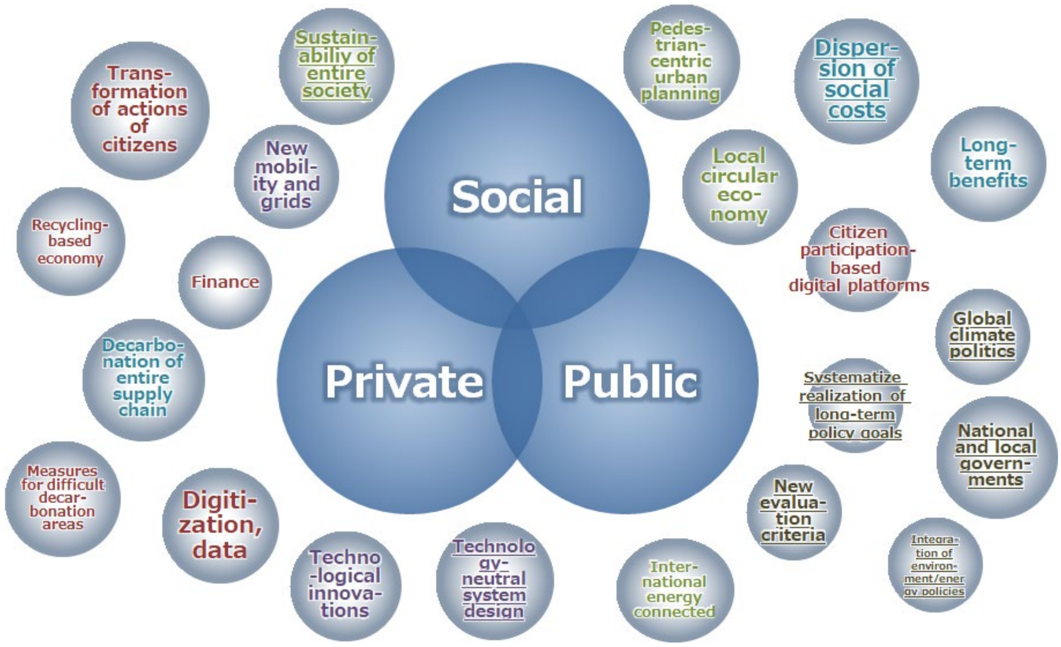

Figure 6-3 Major issues raised in expert interviews

Based on issues raised in expert interviews, the Hitachi-UTokyo Lab is discussing the themes shown in Table 6-1 as critical perspectives related to realizing a CN society by 2050.

Table 6-1 Main themes from expert interviews

Sector	Theme	Noteworthy issues
Social	Pedestrian-centric cities and role of mobility	● In Asia and Africa, population growth and urbanization are progressing, and megacities are expanding. Meanwhile, in major European cities and Japan, cities are becoming compact and pedestrian-centric urban planning is proceeding. ● New mobility such as EV will integrate vehicle-to-grid (VtoG), AI, and smartphones. Its role will be changed by its connection to disaster resilience, renewable energy, and the sharing economy. ● Improving the quality of public transportation, including railways, is a new issue of focus. It is connected to changes in local lifestyles, urban structures, and mobility.
	Citizen Participation and local infrastructure	● Citizens' proactive participation will greatly influence decision-making related to local infrastructure, including the deployment of renewable energy, and become an important factor in the establishment of a local circular economy. ● Digital platforms are effective tools for supporting data-based urban planning, infrastructure operations, and decision-making by citizens.

	Sustainability and new view of well-being	● The climate crisis is connected to sustainability issues such as resilience, biodiversity, circular economy, and gender and racial equality. It will have greater impact as an important principle concerning how people consume, work, and participate. ● It will be important to establish a new view of well-being that is consistent with the sustainability of the global environment instead of economic growth and mass consumption.
Private	Decarbonation of finance and supply chains; transformations of industrial structures	● International socially responsible investment networks and finance will have increasingly heavy influence on corporate valuation, and strongly promote CN in the supply chains of giant corporations. ● The expansion of the scope of companies' decarbonization criteria will have a significant impact on global companies' selection of business partners and create opportunities for the rapid transformation of industrial structures. Delays in responding (lock-in) will greatly threaten the international competitiveness of Japan's industries.
	Promotion of renewable energy	● To achieve CN-related goals, new renewable energy businesses entries and cost reductions for consumers must be stimulated. So that this prerequisite is not hindered, the existing market design must be further improved to prepare for rapid changes in supply and demand due to geopolitics and weather conditions. ● To enable EVs to sufficiently fulfill their function of supporting renewable energy through linkages with the power systems of local communities, mutual data linkages must be standardized. ● There is a great shortage of experienced, specialized human resources in Japan for advancing renewable energy. It is therefore necessary to create a mechanism to enable multilayered expansion of talented groups in each field.
	Decentralization through integration of energy and IT	● The integration of energy systems and IT will result in the entry and development of new actors and distributed services. It may result in a path similar to workings of the telecommunications industry over the past 30 years.
Public	National and local government decision-making	● The rapid transformation by distributed renewable energy will create tension between the central and local governments. It will be necessary to create a system to realize sustainable development through the understanding and participation of citizens, based on the environment and economy specific to each region. ● Local governments can play a role in preventing conflicts and promoting a fair process by acting as the intermediary between local citizens businesses inside and outside Japan.

	● The government should form a framework that allows not only existing energy providers but also new actors promoting decarbonization to participate in policy-making.
Integrated promotion of environment and energy	● Achieving CN is a long-term goal. A mechanism to realize environment and energy-related policies in an integrated manner will be effective for realizing the goal. ● Besides assigning specialized human resources in a fluid manner as the Japanese government's planned "digital agency" would, it is desirable that the national and local governments, industries, and citizen groups work together to promote the policies.
Long-term roadmap open to participants	● In the short term, it will be necessary to identify policy and innovation options necessary to achieve the goals. ● It will also be important to develop a long-term roadmap that is open to the public and private sectors and citizens, and continue to revise it while sharing the pathway until the goal is achieved.

The perspectives shown in the table above focus on structures, actors, and decision-making, revealing various conditions occurring today. They include suggestions related to transitioning to CN by 2050. As shown by MLP's framework for analyzing socio-technical systems, at present Japan's fossil fuel-centered energy systems can be seen as containing interconnections between urban development, which is premised on coal and natural gas-based infrastructure for power generation and centralized transmission and distribution and transportation using gasoline-powered cars, and industries and lifestyles premised on mass consumption and mass disposal of petrochemical products, as well as mechanisms for policy formulation by the government in response. However, the acuteness of the global climate crisis has become clear, and the transition to new systems centered on renewable energy from old fossil fuel-centered structures has taken on urgency.

Expert interviews have revealed that new, renewable energy-centered systems promote transformation of the collective action of diverse actors in the social, private, and public sectors. Actors in Japan, including infrastructure providers, manufacturers, and megabanks, have been slow until recent years in actively responding to the Paris Agreement with initiatives due to the great inertia of being tied to the past. Meanwhile, interviewees from new renewable energy providers and regional power companies and those involved in startups promoting new technological innovations and services discussed how they have been building their own relationships with communities and exploring sustainable development under laws, technology policies, market designs, and consumer habits formed under the old structure, and amid difficulties such as barriers to entry and international competition.

However, interviewees involved in corporate information disclosure have stated that as the influence of climate action by civil society grows stronger, international socially responsible investment networks are also exerting stronger influence, seeking disclosure from companies on carbon emissions and using decarbonization efforts as a CSR benchmark. In fact, as investment channels broaden to new actors, conventional actors have made announcements that include plans to withdraw from coal-fired thermal power generation, increasing investments in renewable energy businesses, and abolishing fossil fuel automobiles. And, as conveyed by several interviewees, changes in socially responsible investing and procurement standards have permeated to traditional actors’ entire supply chains. How swiftly actors can respond to these changes will have a major impact on Japan’s industrial competitiveness. In particular, this movement is accelerating not only in Europe and North America but also in Asia, pressuring existing companies in petrochemical and automotive industries to rapidly shift their business portfolios in changing markets. Changes in international affairs due to COVID-19 and new awareness of climate action in Japan are expected to accelerate these actions.

The radical transformation to a renewable energy-centered system amid the climate crisis shows that old ways of decision-making in various fields must change. Renewable energy, which makes use of distributed energy resources, is closely tied to natural conditions such as the topography and climate of a region and to lifestyles and the economy. The rapid expansion of renewable energy thus frequently results in conflicts in local communities. For example, as pointed out by interviewees involved in renewable energy businesses, in local cities tensions have arisen between companies and community residents over the construction of renewable energy generation facilities. Issues include understanding the effects of the construction on the residential environment and on the agriculture, forestry, and fisheries industry. Local governments have the potential to play a leading role in creating sustainable ways of life uniquely suited to their region. Also, as observed by urban data experts, digital platforms for citizens can serve as tools for supporting consensus building.

In the interviews, experts also observed that the decision-making involved in energy policy-making under the old energy system was insufficient for promoting long-term, omnidirectional transition to a CN society. In particular, under the old system energy policy is centered on existing actors. In the new system, on the other hand, policy-making must heed the voices of diverse bodies in civil society and new renewable energy providers, which is difficult at present. Therefore, in order to achieve long-term policy goals, experts opined that it would be effective to have a framework in which an open roadmap is shared among stakeholders such as the national government, local governments, private-sector companies, and civil society to build consensus and revise policies in different areas.

In this way, the expert interviews clarify perspectives in accordance with the concepts of structures, actors, and decision-making that should be heeded in an integrated transition for realizing CN. It is no exaggeration to say that the issues presented here are only a part of the analysis of transition scenarios by the Hitachi-UTokyo Lab. However, they include several themes that we should continue to study to understand long-term social transformations involving energy systems.

Going forward, we will sketch the future vision of 2050 through an analysis of the interviews and facts while conducting analysis of present issues. Based on process, we will develop outlines of transition scenarios by backcasting from the future vision. Then, with feedback from a wider range of stakeholders, we will elaborate the details of the scenarios and develop the overall scenario for the next proposal.

(2) Challenges involved in developing scenarios

Realizing a CN society by 2050 is a long-term goal spanning about 30 years from now. It will require fundamental structural transformations in a wide range of political, economic, and social areas to achieve the goals, as discussed thus far. Therefore, formulating scenarios involving these complex issues and transformations will not be easy. This activity is expected to face a variety of challenges, such as many-angled analysis, discernment of long-term future vision, and transparency of the development process. However, producing transition scenarios as a resource for moving forward to realize the goals on an untrodden path and confirming this path will increase in importance going forward. This endeavor will require working together with diverse actors in a wide range of fields in society and forming the desired vision of the future from various perspectives. In particular, there will be a need to investigate changes required in fields extending across the entire society and the public and private sectors. In this regard, the work of creating resources that serve as reference for many people by researchers of UTokyo, who are continuing to explore diverse academic disciplines, and Hitachi, possessing businesses in a wide range of sectors, through candid exchanges of knowledge and views, will have great significance. With the best knowledge of both partners, Hitachi-UTokyo Lab's effort to develop transition scenarios seeks to contribute to the social challenge of realizing CN in the first half of the 21st century in Japan.

6.4 Summary

- To achieve CN, it is essential to accurately present not the ideal conditions of power utilities and grids but also multidimensional transition in society, including in the areas of cities, daily lives, industrial structures, and decision-making.
- Based on prior case studies and studies of methodologies, the Hitachi-UTokyo Laboratory has begun studying "transition scenarios," which present structural transformations in society and the private and public sectors.
- Going forward, we will develop scenarios based on knowledge held between Hitachi and UTokyo, while dialoguing with a wide range of stakeholders.

Chapter 7: Human Resources Development to Support the Energy System

7.1 New Personnel Development

To develop energy systems that support Society 5.0 while concurrently creating an infrastructural industry that contributes to the society on a global scale, we will need to depict multidimensional transition of society, formulate and implement a multi-scale (i.e., short-, medium-, and long-term) strategy to integrate scientific/technological innovations, social systems, and economic mechanisms. The transformation of energy structures will take time, given its extremely large impact on society and the scale of current infrastructural facilities. However, with the CN declaration due to the climate change issue and the rapid expansion of ICT use due to COVIC-19, we must begin action quickly and complete structural transformation by 2050. To realize this structural transformation, it will be imperative to encourage collaboration among industry, academia, and government to continually invest in the development of human resources capable of discussing the multifaceted values of energy systems and carry out sustained initiatives. This human capital must be developed beyond industrial, academic, and generational lines.

Relevant academic disciplines include not only fields of engineering such as electric, transportation, and information, but cross-over into other areas of study such as economics, business administration, financial engineering, and sociology. Specifically, universities can establish joint education and research programs for energy systems that transcend the boundaries of specialization or graduate school departments. The program will hone the following: the ability to consider the numerous, increasingly complex issues in society from an objective, panoramic perspective; the capacity to discover, ascertain, formulate, and solve problems; and to identify truly important tasks spanning multiple time horizons by viewing the problems from interdisciplinary and temporal (short-term, medium-term, long-term) perspectives. An effective approach to such initiatives would be, for example, to promote a project that aims to solve an energy system issue by combining interdisciplinary expertise, while simultaneously pursuing research and personnel development. Such an approach will allow the project’s achievements to be utilized for other innovations and may give rise to new industries. Furthermore, a system development project could lead to the creation and development of new interdisciplinary knowledge, methodologies, and tools. Maximizing the effectiveness of these initiatives will necessitate strong collaboration and cooperation between universities and the industrial sector.

Industries will also need to implement human resource development through the development of multifaceted energy systems. These human resources are free from sectionalism even in company activities. In addition, they must build a framework to accept and leverage cross-over human resources who enter the industry from university after completing the educational process described above. To develop such cross-over human resources and determine their qualities, it is desirable to create training and evaluation opportunities through mutual discussion. These opportunities would add not only particular technological improvements and service developments but also a wide range of future-oriented themes to joint industry-academic projects.

Such approach to human resources development differs significantly from universities’ conventional approach that instead seeks to cultivate individuals who would be competitive in an international academic landscape. Therefore, it is also necessary to develop relevant evaluation criteria in the industrial sector to measure this new type of human capital. The evaluation criteria may emphasize the social or economic values created by the person’s deliverables or on the processes linking research outcome to value creation. Other evaluation axes could include the proactive evaluation of knowledge application and organizational management abilities.

The human resources development described above will be mainly spearheaded by the industrial sector, national government, local communities, and universities. Furthermore, although short-term tasks will be determined by free market mechanisms, national perspectives and policies will play an extremely large role in the development of human resources to handle medium-and-long-term challenges. In particular, universities assume an important role given their long-term scope. Thus, governmental support for universities is imperative.

7.2 Utilizing Veteran Personnel

Given Japan's rapidly aging population, depicting transition of society, formulating a multi-scope strategy, and implementing multidimensional transition of society should entail the proactive utilization of industry-ready veteran personnel, who are valuable assets. In this way, the team can accelerate the development of local community systems and bulk power systems. In Japan, there are numerous experienced personnel who have supported the supply of highly credible energy and are approaching their retirement ages. Japanese companies face the challenge of technological succession, causing concern over the future decline of technological capacity. On the other hand, some overseas companies have been proactively hiring senior Japanese personnel to enhance their technological capabilities. Furthermore, human resources belonging to the senior citizens group and who are familiar with the latest digital technologies are increasing, making them valuable assets in an ICT society.

Going forward, in response to the transformation of energy systems, it is desirable to prepare an interdisciplinary pool for senior human resources who transcend the boundaries of separate companies in order to supply appropriate human resources for a wide range of situations. In addition, efforts to standardize different technological standards in each company will also be important from the standpoint of securing human resources in light of Japan's declining population and low birthrate. In particular it will be important to utilize senior human resources as innovators connecting industry, academia, and the government in local communities, which will take on the challenges of facing new directions.

Chapter 8 Proposal

Below we summarize the proposal to realize the energy systems that will support Society 5.0.

- Establish diverse energy systems at an early stage to realize CN premised on the participations of all members of society.

  (Chapter 1)

  Changing goals to achieve CN by 2050 requires large-scale reforms beyond electricity systems to encompass all aspects of energy generation, distribution, use and circulation. Challenges will be advanced integration of services such as energy, information, transport, and logistics and promoting reforms with the participation of all members of society.

- Because the processing of transitioning to CN will overlap with a time of great change in Japan, including of the country's social structure, our proposal seeks to ensure multiple technological and commercial options for decarbonation and explore pathways for the transition process premised on the participation of all members in society.

  (Chapter 2)

  For the transition, it is critical that industry, academia, and government work together as one to create the transition roadmap, including plans that should be achieved by 2030. The roadmap should make effective use of existing social infrastructure, consider the social infrastructure and the industrial sector in association with the transition from fossil fuels, study the coexistence of resource circulation and the value cycle, and examine cities and citizens' lives that are compatible with both daily life convenience and CN.

- Implement an energy data utilization system that allows everyone to participate and provides value to local communities and bulk power systems while supporting decarbonation.

  (Chapter 3)

  To solve issues of local communities due to social changes since the release of Version 2, the proposal implements an energy data utilization system that allows everyone to participate and achieves both support of decarbonation and provision of value to regional and bulk power systems. It presents a transition process that should be realized to provide benefits to stakeholders incrementally and achieve a virtuous cycle of investment, benefits, and reinvestment.

- Deploy large quantity of renewable energy necessary for decarbonation based on measures at the societal level, including up to induced demand placement, such as hydrogen production.

  (Chapter 4)

  To support decarbonation of society, we must introduce over-300GW variable renewable energy sources as energy sources to meet increased demand due to electrification of previously non-electrified machinery. To ensure supply and adjustment of energy in response to uneven distribution and fluctuations associated with renewable energy, it is also necessary to produce and utilize hydrogen. Given that resources for solar and wind power generation are region-dependent, and considering the limits of energy transmission based on system stability, we should prepare for the deployment of renewable energy by not only strengthening systems and improving control methods, but also by introducing measures at the social level, including guiding the placement of demand with hydrogen production.

- Establish evidence-based policy-making and build an international framework toward realizing the vision of achieving CN

  (Chapter 5)

  To identify development and investment areas necessary to achieve CN, the future vision of energy systems must be fleshed out to identify what developments and investment areas are needed. A mechanism must be built to circulate funds and promote innovation, and a long-term, scientific evidence-based energy strategy should be developed. It is also desirable that national interests are reflected in national boundary adjustments and rule-making within and outside Japan. Also important is making carbon pricing visible and sharing communication about it among the international community.

- To steadily realize a decarbonized society, it is necessary to develop and share "transition scenarios" that show the path of integrated structural transformation to be achieved in each sector.

  (Chapter 6)

  To achieve CN, it is essential to accurately present multidimensional structural transformation, including not only power systems and distribution grids but also cities, lifestyles, industrial structures, and decision-making. Developing transition scenarios to realize a decarbonized society from the ideal forms of the social, private, and public sectors in 2030 and 2050 is critical. The Hitachi-UTokyo Lab will present the process for developing scenarios.

- Development of cross-functional human resources with the collaboration of industry, academia, and government

  (Chapter 7)

  To build an energy system that supports Society 5.0 and create an infrastructure industry that contributes to the global community, it is important to assess scientific and technological innovation, social systems, and economic mechanisms as an integrated whole. Industry, academia, and government must work together to promote efforts beyond industrial, academic, and generational boundaries, and foster human capital capable of discussing multifaceted values. It will also be important to utilize seasoned professionals, who are valuable assets in Japan.

Team Members of Proposal Version 3 (as of January 18, 2021)

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

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

[Appendix 1] Discussion of visions of cities under technological transformation scenarios

1. Urban concentration and decentralization

In Version 2, we examined energy scenarios by assuming “urban concentration,” whereby the population of Japan becomes concentrated in three major metropolitan areas in Japan by 2030, and “decentralization,” whereby local communities are formed around core cities. In April 2019, there were 55 core cities. As of January 2021 there were 60 core cities, and 12 cities are making preparations to be core city candidates.[50] A simple calculation shows that there is at least one core city in each prefecture. As their designation indicates, core cities can be expected to fulfill core functions of the national government delegated to them.

Population outflow from Japan’s regions occurs for various reasons. We discussed population estimates based on the “dam effect,” in which the core cities in each region absorb population outflow instead of uniform outflow from the regions to the three major metropolitan areas of Tokyo, Nagoya, and Osaka. Figure I-1 shows the results of the population estimate of Ibaraki Prefecture as a case study. In Ibaraki Prefecture, Mito City is a core city and Tsukuba City is a core city candidate. Tsukuba City, in southern Ibaraki, is expected see its population increase from 2015 to 2040 due to the impact of the Tsukuba Express railway line. Mito City, in central Ibaraki, is expected to experience population decline by 13.3% by 2040. This decline is lower than the entire prefecture’s average population drop of 30.5%. Ibaraki cities, towns, and villages north of Mito City are experiencing population decreases at rates greater than 50%. It is surmised that a portion of this population is outflowing to Mito City, forming a broad area between northern Ibaraki and Mito City. As a rule, Tsukuba City is incomparable, as it is experiencing population inflow from outside Ibaraki besides population inflow from surrounding cities and towns in the prefecture. A broad area that extends from western to southern Ibaraki is thus also being formed.

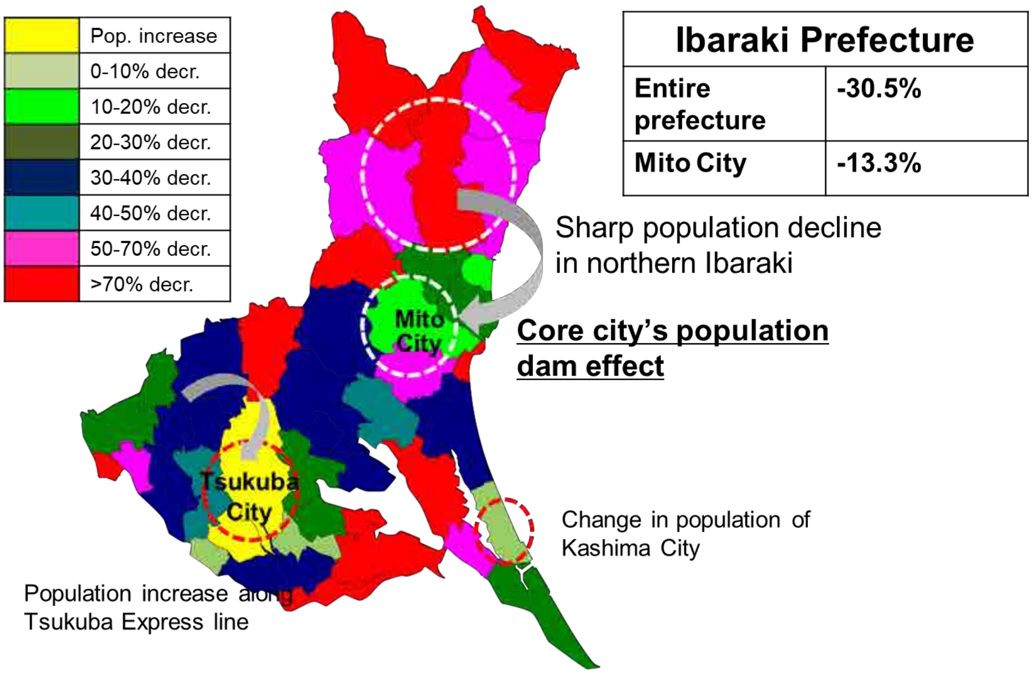

Figure I-1. Population estimates and population changes in Ibaraki Prefecture (2040 population estimates based on 2015 figures)

[50] *Chuukakushi shitoyoukai* (Council of core city mayors) https://www.chuukakushi.gr.jp/

2. Discussion of Energy consumption in the process of population decline

We discussed energy consumption in population decline, using Akita Prefecture as a case study. Akita currently is experiencing the highest rate of population decline in Japan. Figure I-2 shows population and total energy consumption trends in Akita from 1990 to 2017. Figure I-3 shows energy consumption trends by group. As the red box indicates, total energy consumption has been decreasing along with population from 2005. By group, energy consumption is correlated to the population trend only for households and the transportation sector; business, manufacturing, agriculture/forestry/fisheries, and mining sectors show flat trends.

In a situation where the industrial structure within the region does not collapse, we believe that a certain amount of energy demand can be built in each region, and that an appropriate energy distribution can be constructed by coordinating with the power systems of these industries. In a situation where a region does not experience industrial collapse, we believe that in each region a certain level of energy demand can be expected, and that appropriate energy distribution can be implemented by coordinating the power systems of these industries.

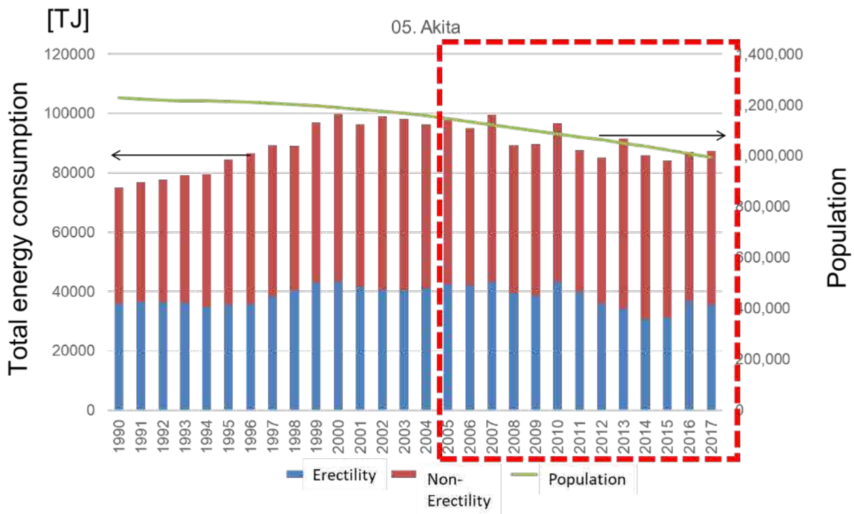

Figure I-2. Population energy consumption trends in Akita Prefecture

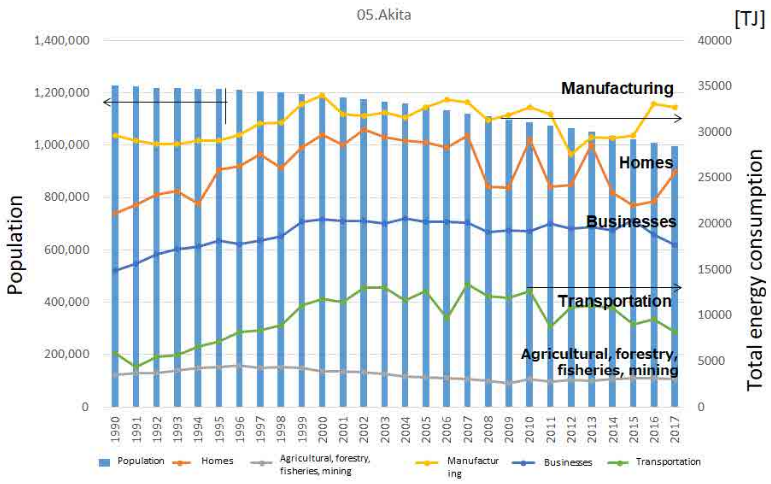

Figure I-3. Population (bars) and sector energy consumption trends (lines) in Akita Prefecture

[Appendix 2] Quantitative evaluation of power distribution grid measures in connection with deployment of renewable energy and electrification and their reflection in urban planning

As stated in Chapter 3.2, the main infrastructure for energy supply and demand until the 2030s is the electricity system. A challenge is therefore avoiding overload of power distribution grids in response to increased demand for electricity due to the spread of electrification, including electric vehicles (EVs). As examples of the use cases of the distributed energy resource (DER) coordination and control platform presented in this proposal, we quantitatively evaluate conditions of power distribution grids in 2050, when solar power generation (photovoltaic PV generation), EVs, and heat pumps (HPs) are expected to be deployed in large numbers. We present calculations of the impact of PV, EVs, HPs, as well as EV fast charging on power distribution grids and give examples of response measures.

1. Impact of PV, EVs, and HPs on power distribution grids in 2050

A local community can be largely divided into residential, commercial, and industrial areas, with different amounts of PV, EVs, HPs, etc., deployed in each area. Table II shows the characteristics of the load electricity and grid configurations for residential, commercial, and industrial areas. In a residential area, home PV, personal EV, and home HP make up a large percentage of the power distribution grid. In a commercial area, business HPs and freight EVs make up a large percentage. There is also a large difference between daytime and nighttime energy demand. Meanwhile, in an industrial area the proportions of industrial HPs and freight EVs are high. We selected model cities based on land use proportions and daytime/nighttime populations. Next, we determined the annual energy consumption in each area (residential, commercial, and industrial) from energy consumption statistics of the prefectures to which the model cities belong and information on land use. We developed electrical load models based on the standard load patterns for different purposes and by season (summer, winter, and intermediate seasons).[51] We also decided the feeder ratio for each purpose based on the electrical load, and the number of substation transformers from the maximum electrical load. Figure II-1 shows the distribution grid configurations used in this analysis. For the feeder configuration, we used the standard feeder configuration for each purpose.[51] Referencing various reports, we assume in Japan in 2050 259GW in solar power generation,[52] 44 million EVs,[53] and 1,000GW for HPs.[54] We then determined the capacity of PV, EVs, and HPs in each area from model cities, the number of households in Japan, and the land use proportions (Table II-2). For the EV electrical load, we determined the average energy consumption per EV from daily automobile travel distance data[55] and power consumption (km/kWh, equivalent to gasoline car fuel consumption) data. We then calculated the amount based on the number of EVs in each city to calculate total energy consumption. We assumed nighttime charging, when the impact on users' convenience is low. For electrical load of HPs, we referenced survey reports.[54] We assumed that the continuation of the current state in which heating

[51] The Institute of Applied Energy. 2006. "New electricity network system verification research: Comprehensive survey of new electricity network technologies -- Progress report (Part I)" (in Japanese). https://www.iae.or.jp/wp/wp-content/uploads/2014/09/network/vol1.pdf

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

[53] National Institute for Environmental Studies. 2020. "Preliminary calculations for realization of decarbonized Society by 2050" (in Japanese). https://www-iam.nies.go.jp/aim/projects_activities/prov/2020_2050Japan/2050_Japan_201214.pdf

[54] Heat Pump & Thermal Storage Technology Center of Japan. 2020. "FY2020 report of estimate of penetration of heat pumps" (in Japanese) https://www.hptcj.or.jp/Portals/0/data0/press_topics/2020NewsRelease/news_release_siryo.pdf

[55] Iwafune, Yumiko and Takashi Ikegami. 2018. "Study of energy consumption in automotive sector in 2050" (in Japanese), 34th Conference on Energy, Economy, and Environment, Japan Society of Energy and Resources

by HPs uses nighttime electricity. We hypothesized that cooling and heating HPs for offices and factories would be used during daytime business hours, and that each type of electrical load and PV generation are evenly distributed in power distribution grids.

Table II-1 Model of grid for each area

Type	Aim	Selection conditions	Selected city	Load power*	Grid configuration
Residential area	Study issues related to spread of solar power generation for homes, private EVs, home HPs	･Large proportion of residential land use: 90% ･Heavy use of private cars: weekdays 35%, holidays 55% ･Low city gas penetration rate: 69% (Possible to promote electrification)	Machida City	Max. 567MW Power usage proportion Residential: 64% Commercial: 34% Industrial: 3%	Substation transformers - 10 ×3 banks ×(Feeder for Residential - 4 ＋Feeder for Commercial - 2)
Commercial area	･Study issues related to spread of HP for businesses, freight EVs ･Study differences in day/nighttime demand	･Large proportion of commercial land use: 77% ･High daytime pop.: 610,000 ･Low nighttime pop.: 140,000	Chuo Ward (Tokyo)	Max. 683MW Power usage proportion Residential: 1% Commercial: 98% Industrial: 0%	Substation transformers - 12 ×3 banks ×Feeder for Commercia - l6
Industrial area	Study issues related to spread of industrial HP, freight EVs	･Large proportion of industrial land use: 45% ･Small proportion of land use for commercial: 4%	Kashima City	Max. 365MW Power usage proportion Residential: 14% Commercial: 15% Industrial: 70%	Substation transformers - 7 ×3 banks ×(Feeder for Residential - 1 ＋Feeder for Commercial - 1 ＋Industrial feeders - 4)

*Figures are rounded to whole numbers, so the total may not add up to 10.

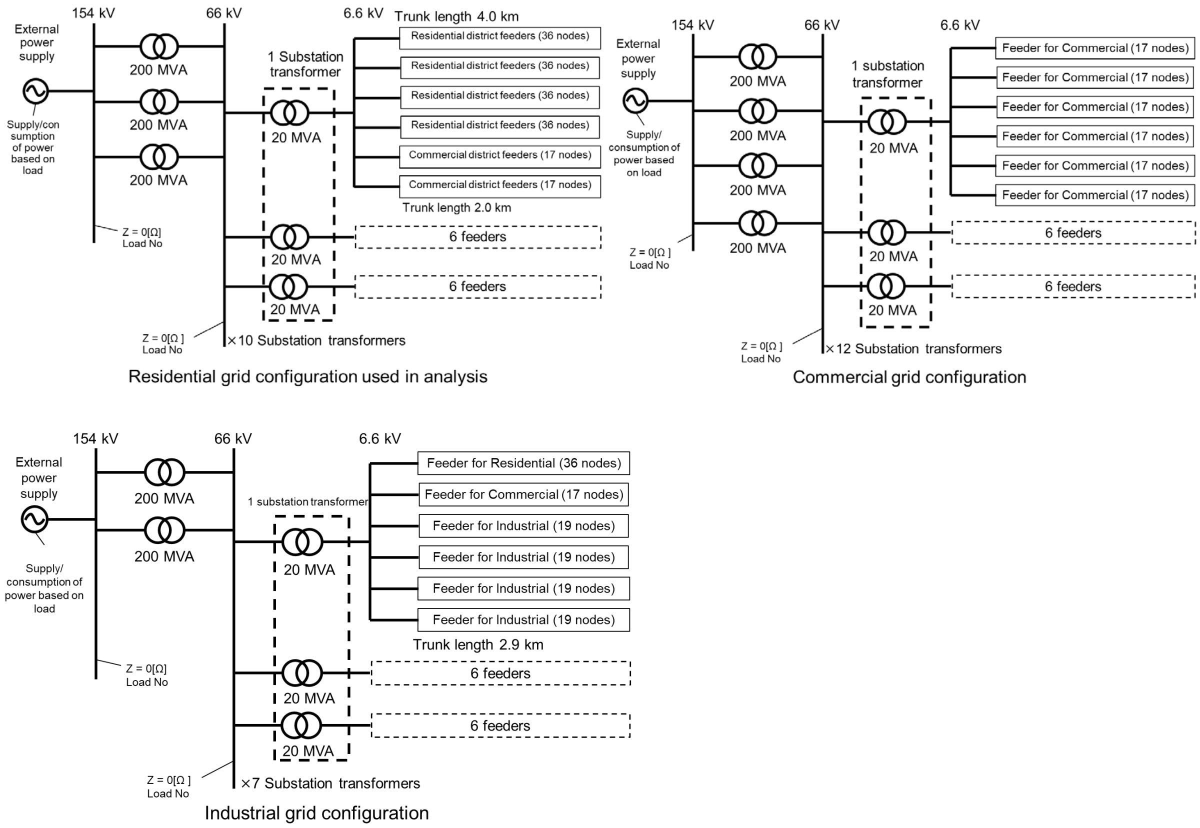

Figure II-1 Grid configuration used in analysis

Table II-2 Capacities of PV, EVs, and HPs in each area

	PV	EV	HP
Residential	279 MW	140,000 units	3,110 MW
Commercial	213 MW	75,000 units	2,220 MW
Industrial	99 MW	24,000 units	850 MW

Figure II-2 shows the results of evaluating the impact on power distribution grids by a residential area during the summer and in sunny weather. Residentials areas have more noticeable impact on power distribution grids. The total daytime load is smaller than the nighttime load due to the large-scale deployment of solar power generation. The voltage of distribution lines and maximum usage rate are maintained within appropriate ranges. However, the load increases due to nighttime EV charging and heating by HPs, and from 10 p.m. to midnight overload occurs at substation transformers. Table II-3 shows the results of calculating the facility costs of power distribution grids in a residential area from the unit cost of transmission and transformation equipment,[56] equipment capacity, number of units, and distance of installations. If the load is not controlled, it will be necessary to increase the capacity of substation transformers.

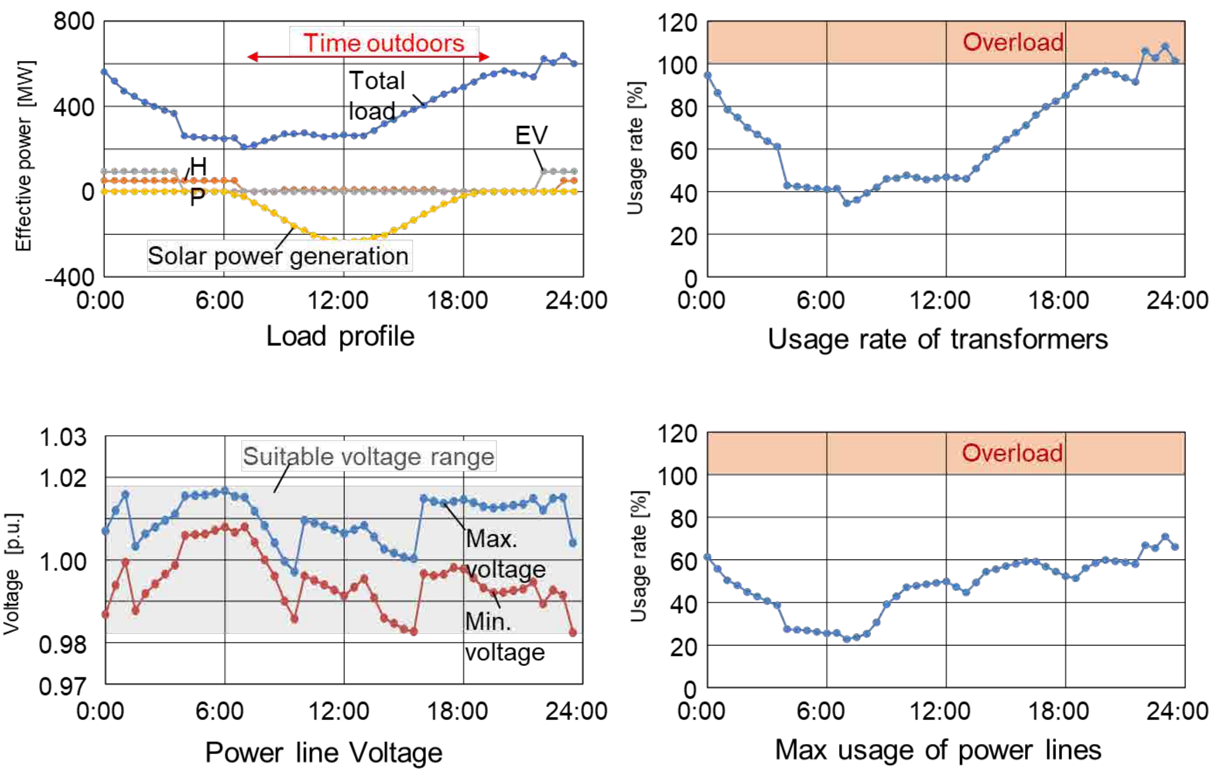

Figure II-2 Results of evaluation of residential area during summer period in 2050

[56] Organization for Cross-regional Coordination of Transmission Operators, JAPAN. 2016. "Public announcement of standard unit prices for transmission and transformation equipment" (in Japanese). https://www.occto.or.jp/access/oshirase/2015/files/20160329_tanka_kouhyou.pdf

Table II-3 Calculation of facility costs of power distribution grids in residential area

	Existing	Increased facilities
Transformers	1.2 bil. yen	200 mil. yen
Puller facilities	30 mil. yen	10 mil. yen
Overhead lines	21.81 bil. yen	0.0 mil. yen
Total	23.04 bil. yen	210 mil. Yen

Figure II-3 shows an example of evaluation results where the electrical load is equalized by the distributed energy resource (DER) coordination and control platform in order to avoid adding power distribution grid facilities. Compared to Figure II-2, in Figure 3 EV charging is changed to an early morning from nighttime, and HP heating is changed to daytime from nighttime. These changes result in the elimination of overload of transmission and transformation equipment.

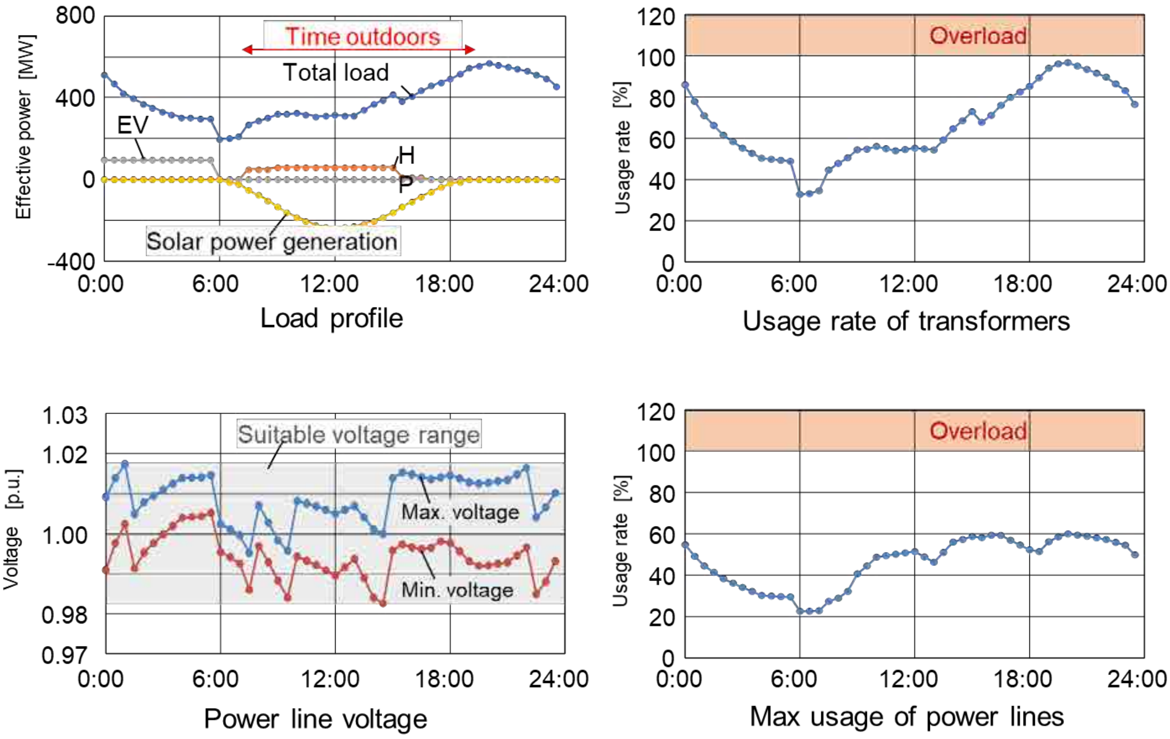

Figure II-3 Results of evaluation of residential area during summer period in 2050 after applying DER coordination and control platform

Table II-4 shows the results of evaluating the maximum usage rates of transmission and transformation equipment in each area as a summary of the impact by PV generation, EVs, and HPs on power distribution grids. In sunny weather, the maximum usage rate of substation transformers can be reduced by DER control. On the other hand, during rainy weather, there are cases where DER control increases the maximum usage rate of substation transformers. DER coordination and control in this evaluation changes EV charging to early morning from nighttime and HP heating to daytime from nighttime. We confirmed that it is necessary to control DER based on the amount of solar power generation and load.

Table II-4 Evaluation results of maximum substation transformer usage rate in each area

Sunny weather

Season	Summer		Winter		Intermediate	
DER coord./control	No	Yes	No	Yes	No	Yes
Residential	107%	95%	82%	72%	70%	60%
Commercial	85%	84%	67%	66%	61%	52%
Industrial	84%	84%	54%	54%	47%	47%

Cloudy weather

Season	Summer		Winter		Intermediate	
DER coord./control	No	Yes	No	Yes	No	Yes
Residential	107%	96%	82%	72%	70%	60%
Commercial	94%	100%	69%	69%	64%	67%
Industrial	93%	96%	61%	62%	55%	56%

Overloads are not listed.

2. Impact of EV fast charging on power distribution grids

Taking into consideration the penetration of EV fast charging in 2050, we calculated the impact of EV fast charging equipment on power distribution grids (Table II-5). Here we list the maximum usage rates of transformers during summer, winter, and intermediate periods. The electrical load and system configuration of each area are the same as in previous calculations. We assume the rated capacity of an EV fast charger to be 350kW.

During sunny weather, the maximum usage rate of substation transformers increases in relation to the penetration rate of fast charging equipment. With 100% penetration, overload occurs in 35% of the model residential area and 11% of the commercial area. Also, because solar power cannot be generated in rainy weather, the maximum usage rate of substation transformers further increases. With 100% penetration, overload occurs in 51% of the residential area, 22% of the commercial area, and 9% of the industrial area.

As countermeasures, the DER coordination and control platform controls the charging schedule of fast charging equipment and number of units during peak load time. As shown in [ ] of Table II-5, overload of substation transformers can be reduced by controlling the upper limit of fast charging usage during peak load time.

The evaluation shows that charging at the rated capacity cannot be achieved even with the installation of fast charging equipment, resulting in a time period when charging is limited. Urban planning must therefore take in consideration the amount of limitation and length of limitation. This issue of output limits is shared by many cities. Therefore, an evaluation platform that can assess various models of residential, commercial, and industrial areas and be openly used should be implemented.

Table II-5 Changes in maximum usage rate of substation transformers due to penetration of EV quick charging equipment

Sunny weather

Fast charging penetration rate*	10%	50%	100%	
DER coord./control	No			Yes
Residential	107% (Night: Normal charging)	107% (Night: Normal charging)	135% (Day: Rapid charging)	95% [Upper lim. 35.8%]
Commercial	86%	97%	111% (Day: Rapid charging)	95% [Upper lim. 43.0%]
Industrial	85%	91%	99%	95% [Upper lim. 73.9%]

Cloudy weather

Fast charging penetration rate*	10%	50%	100%	
DER coord./control	No			Yes
Residential	107% (Night: Normal charging)	119% (Day: Rapid charging)	151% (Day: Rapid charging)	95% [Upper lim. 11.4%]
Commercial	97%	108% (Day: Rapid charging)	122% (Day: Rapid charging)	95% [Upper lim. 2.4%]
Industrial	95%	101% (Day: Rapid charging)	109% (Day: Rapid charging)	95% [Upper lim. 10.4%]

Overloads are not listed. Main cause shown in ( ).

[Appendix 3] Methodologies of Transition Scenarios

a. Existing energy scenarios

1. Gap between global outlooks and normative scenarios

At present, as the climate situation becomes increasingly severe, various energy-related organizations and research institutes around the world are developing and have presented scenarios of decarbonation goals and energy demand in the future. Recently, the International Energy Agency (IEA) released a detailed report on global CO_2 emissions and energy demand in the future in order to curb the global warming of 1.5°C estimated by the Intergovernmental Panel on Climate Change (IPCC)'s[57] The IEA's 2020 report visualizes reduction in CO_2 emissions necessary for achieving previously presented scenario goals in the future. The scenarios shown are the Stated Policies Scenario (STEPS), the Paris Agreement's Sustainable Development Scenario, and the IEA's own Net Zero Emission by 2050 Case, which seeks to achieve CN by 2050 (Figure III-1). However, one must pay attention to the fact that even though these cases are termed "scenarios," they differ between each other in how they treat the relationships between current conditions and future goals.

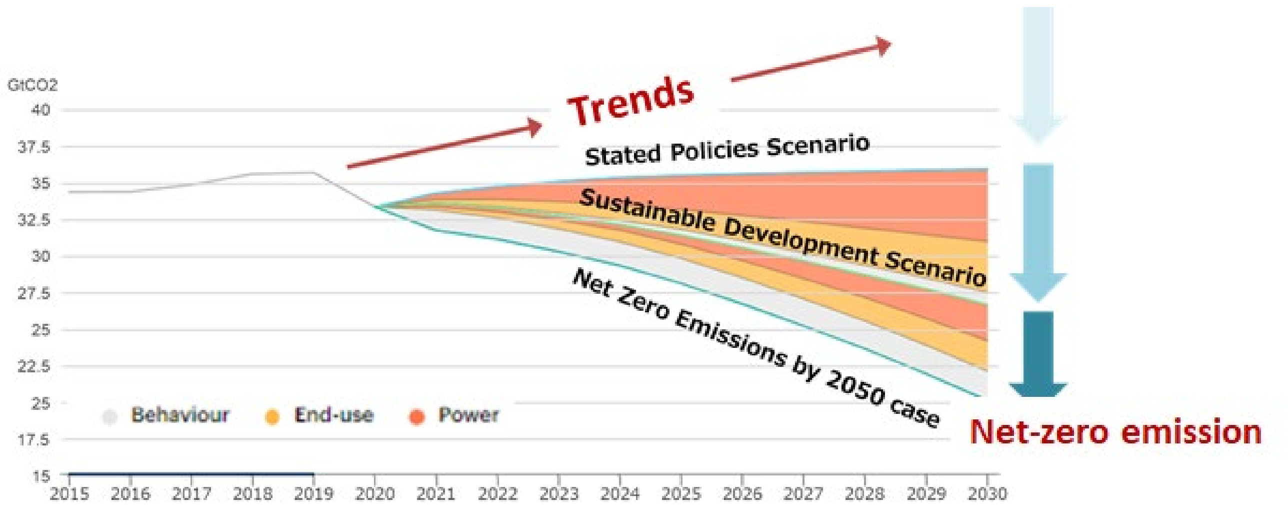

Figure III-1 IEA's visualization of global CO_2 emission reduction scenarios (2015-30)[58]

In a report published in 2019, the World Energy Council (WEC) categorized and compared major energy scenarios from around the world (Table III-1). WEC classified the energy scenarios presented by various organizations, research institutes, and companies into three categories: (1) plausible scenarios, (2) outlooks, and (3) normative scenarios.

(1) "Plausible scenarios": Presentation of plausible pathways, regardless of whether or not they are ideal, that may occur under multiple future-related contexts. Presenting qualitative narratives (stories) and reference figures, they often describe not only technological and economic aspects of the future but also social and political elements.[59]

[57] International Energy Agency. 2020. World Energy Outlook 2020. (https://www.iea.org/reports/world-energy-outlook-2020)

[58] International Energy Agency. 2020. (https://www.iea.org/commentaries/as-we-mark-the-paris-agreement-s-5th-anniversary-we-continue-to-expand-our-work-on-energy-and-climate)

[59] The emphasis is on providing a clear framework to leaders for dealing with uncertainties by presenting various visions of the future that diverge along the time axis.

(2) “Outlooks”: Predictions based on detailed data, presenting visions of expected future or a future that can be assumed based on current trends. In this respect, they are synonymous with “business-as-usual” scenarios. With a focus on technological and economic elements, they carry out mainly quantitative analysis and allow decision-makers to interpret baseline predictions by conducting acceptability and cost-benefit analyses.[60]

(3) “Normative scenarios”: Presentations of desired future for achieving goals with available technologies. Energy scenarios focus on achieving specific goals in the form of a global vision-based agenda. An agenda is formulated based on the presenting organization’s identity, values, and capabilities, and is created by beginning with clear goals in mind and backcasting to achieve them. A challenge here is how to move “business as usual” trends closer to the future desired by the organization.

Seen in the light of this classification, it is necessary in Japan—which has set the goal of CN—to not only understand accurately the gaps between outlooks, in which CO_2 emissions proceed as-in under current trends, and normative scenarios, which present pathways for realizing decarbonation goals. Also necessary is studying from multiple perspectives what measures are possible to sufficiently close the gaps.[61]

Table III-1 WEC’s classification of scenarios[62]

可能シナリオ Plausible scenarios	見通し Outlooks	規範シナリオ Normative scenarios
• Plausible pathways of alternative future contexts that **might happen** whether or not we want them	• Data rich projections – **the future we expect/assume** on a business-as-usual projection of current trends	• Technically possible and **preferable future towards a target**
• **Qualitative based, narrative-led,** supported with **illustrative numbers**	• **Quantitative led**	• Focus on achieving a **specific goal** aligned to a global vision agenda
• Explicit about **societal and political elements** in addition to techno-economic elements	• Focus on **techno-economical elements**	• **Values and identity-based approach**
• Provide a **clear and enabling pre-decision framework** for leaders to engage with uncertainty	• Provide a **sensitivity analysis & enable cost-benefit analysis** for decision makers to compliment the baseline projection with new policies	• Generated by starting from a clear objective/target and back-casting to identify the pathway for making progress (i.e. road mapping)
Assumptions **STORIES** *Future already emerging, whether we want them or not* → Plausible future / Plausible future / Plausible future / Plausible future	*Facts* **A MODEL** *Conditional projection of the expected future* → Upper/best case / Reference/baseline / Lower/worse case	*Capabilities and values* **ORGANISATION/SYSTEM TODAY** *What has to be done to close the gap and achieve specific goals?* → Preferable future / { GAP / Business as usual

2. Attempt to envision “net-zero” society in Japan

As stated above, achieving the goal on CN in Japan by 2050 requires not only technological conditions to be met but also simultaneous economic, social, and political transformations. Therefore, to more concretely present the goals, besides quantitative analysis of the period from the present to the future, also necessary are scenarios to qualitatively present the vision of the future and the strategic process to reach it. However, quantitative analysis has been the

[60] Oftentimes, data based on facts and models are presented with upper-, reference-, and lower-range values.
[61] With regard to CO_2 emissions, it must be noted that the total amount of CO_2 emitted and accumulated in the atmosphere has a significant impact on climate change. Thus if the state of emissions continues on a pathway that does not reach desired goals, as time goes on efforts to reduce emissions at a faster pace will be required.
[62] World Energy Council. Innovation Insights Brief: Global Energy Scenarios Comparison Review. (https://www.worldenergy.org/publications/entry/innovation-insights-brief-global-energy-scenarios-comparison-review)

mainstream method for discussing the systems—including energy systems— desired in the future, and materials qualitatively presenting the features of the desired future have been limited.

Against this background, the Institute for Global Environmental Strategies (IGES) published a fascinating report in 2020 titled *A Net-Zero World -2050 Japan-: Insight into essential changes for a sustainable future* (draft). This report presents two visions of the future in 2050 for the purpose of raising the social issue of CN in Japan. It envisions and contrasts two states, a “transition scenario” in which wide-ranging social transformations occur as part of realizing a net-zero society, and a “locked-in scenario” in which almost no social transformation occurs due to various circumstances (Table III-2).[63]

What is particularly interesting in this perspective of transition to CN in Japan is that the scenarios present not only quantitative analysis of energy demand but also qualitative descriptions of integrated changes to achieve the transition to decarbonation. These descriptions include the perspectives of “people’s thoughts and actions,” “cities and regions,” “living (lifestyles and work styles),” “industries,” and “adaptation (improving resilience).”[64] As indicated by the word “draft” in the title, the descriptions are quite brief. There are also no detailed descriptions of stages for realizing the transition and specific roles of actors. However, it is noteworthy that the report considers transition as multidimensional social transformation and makes clear the importance of presenting the vision in each dimension, including citizens’ lives, cities, and industries.

Focusing on a wide range of social transformations can be considered to be the approach used by the United Nations Sustainable Development Goals (SDGs) to promote simultaneous, multidimensional changes in societies.[65] Represented by 17 goals and 169 targets, SDGs encompass a wide range of economic, social, and environmental challenges facing humankind. The goals are not completely independent of one another but are considered to be intertwined and interconnected. The critical goals of anti-poverty, human rights, and biodiversity, for example, are therefore presented as goals that should be achieved simultaneously while taking into account their interconnectedness. Under this perspective then, energy-related social transformations should be considered in tandem with changes in various other facets of society to realize sustainability. The transition to a CN society should therefore not contradict other efforts to realize sustainability.

To identify the necessary transformations to realize CN in Japan, we must commence more detailed discussions, referencing the above materials.

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[63] Please note that the concept of “transition scenario” in the IGES report and “transition scenario” presented later in this section differ, although they share the same nomenclature. IGES’s term is the specific name for the hypothetical description of conditions for achieving the transition to a “net-zero society” in Japan. The latter term, on the other hand, describes a general method for depicting the process of transition to sustainability and the products produced by that method.

[64] For this proposal, our work of depicting the future vision is based on inclusion of factors related to long-term changes in Japan, based on elements of long-term social transformations discussed in the reports of international organizations published to date. These factors include: a declining population and aging society with low birthrate, concentration of functions in cities, decarbonization, improvement of resilience, recycling-based society, and digitalization.。

[65] United Nations, Department of Economic and social Affairs, “Transforming Our World: the 2030 Agenda for Sustainable Development.” (https://sdgs.un.org/2030agenda.)

Table III-2 IGES' comparison of "locked in scenarios" and "transition scenarios"[66]

Perspective of analysis		Locked-in scenario	Transition scenario
People's thoughts and actions	Values	Ownership values	Functional values
	Economy	Economic rationality	Economic rationality, environmental rationality, increased desire for quality of life
	Resilience	Increased awareness of safety and disaster prevention	Increased awareness of safety and disaster prevention, visualization and internalization of social cost of carbon (SCC)
Cities and regions	Cities and regions/land use	Sprawl development, no changes in land use	Consolidation of urban functions, selection and concentration of infrastructure (simultaneous decarbonation and improvement of resilience), effective use of idle land (for renewable energy, afforestation)
	Transit, modes of transportation (mobility)	Automation, partial electrification	Electrification, automation, promotion of use of public transport
	Local governments	Halted expansion of net zero cities	Expansion of net zero cities, collaboration of cities and regions
	Energy use	Spread of ZEB (net Zero Energy Building) and ZEH (net Zero Energy House) to some homes and office buildings	ZEH for majority of people in Japan, promotion of ZEB for office buildings by taking advantage of opportunities such as rebuilding, electrification of needed energy for heating and cooling, indoor heating by using waste heat in cold regions
Living (lifestyles and work styles)	Holidays, free time	Maintenance of current state of holidays and free time	More holidays and free time, investment in self-actualization
	Consumption	Ownership of products	Consumption of functions and services, sharing (cars, durable goods)
	Purchasing	Improved efficiency of purchasing through digitization (AI, IoT, etc.)	Improved efficiency of purchasing through digitization (AI, IoT, etc.), health consciousness, visualization and internalization of internalized social cost of carbon (SCC)
	Work	Spread of online meetings to some extent	Progress in working from home and use of online meetings
	Production and disposal (waste/resource issue)	Mass production/mass disposal, current resource circulation	Formation of recycling-based society, customized demand flow manufacturing (deployment of 3D printers, etc.)
	Energy use	Life as consumer of energy handled by the supply side in matters of energy use.	Application of demand response-related technologies, life as prosumer of energy who applies demand in harmony with fluctuations in renewable energy.

[66] IGES. 2020. *A Net-Zero World -2050 Japan-: Insight into essential changes for a sustainable future* (in Japanese; draft), p. 24

Industries	Manufacturing and other industries	Improved efficiency of production methods and processes, introduction of low-carbon technologies, electrification	Improved efficiency of production methods and processes, introduction of decarbonation technologies (replacement of existing technologies), promotion of electrification
	Energy use	Dependency on fossil fuels, progress in energy conservation with advancements in technology	Renewable energy-centric, progress in energy conservation with advancements in technology
	Agriculture, forestry, and fisheries industry	Efficient management through digitization (AI, IoT, etc.)	Efficient management through digitization (AI, IoT, etc.), electrification of agricultural/forestry machinery and fishing vessels, provision of services such as fuel cell conversion, provision of raw materials for new materials, power generation, and heating facilities.
Adaptation (improving resilience)	Adaptation measures	Control-centric	Minimization of harm, transformative adaptation
	Integration of mitigation and adaptation	Limit to responding to Task Force on Climate-related Financial Disclosures (TCFD)	Synergy with mitigation, simultaneous decarbonation of infrastructure and improvement of resilience
	International trends, business practices, norms	Control-centric	Major changes in corporate behavior due to legislation of TCFD (Europe), internalized social cost of carbon (SCC) actions
Electricity	Power supply configuration	Continued use of fossil fuels with CCS	Diverse renewable energy-centric
	Power systems, transmission networks	Centralized power supplies, existing power systems	Distributed power supplies, expansion of transmission networks, P2P transactions, demand response, practical application of VPP

b. Transition scenarios

Referencing analysis of energy scenarios from around the world and discussions on the realization of CN in Japan as discussed above, the Hitachi-UTokyo Lab is investigating methods on developing normative scenarios to contribute to the transition to a decarbonized society.[67]

Using "scenarios" as a tool to gain strategic insights into an indeterminate future is connected to the necessity of various social transformations in order to transition to a sustainable society. The Hitachi-UTokyo Lab considers "transition scenarios" as a promising form of scenarios for realizing CN. Transition scenarios provide an exploratory and normative approach to arriving at the "desired future."

According to Saartje Sondeijker, an author of detailed research papers in this field, transition scenarios use "third generation" scenario methodology. This methodology was born from the challenge of considering how to build a sustainable society, which emerged as a critical issue after the 1987 Brundtland Report and 1992 Earth Summit.[68] According to Sondeijker, previous scenarios emphasized predicting an indeterminate future and forming strategies in response. However, the actions resulting from the scenarios did not necessarily lead to a sustainable future. Transition scenarios, on the other hand, orient thinking toward structural social transformations with the aim of sustainability. They stress integration, recognition of uncertainty, and emphasis of normativity and inclusivity. These scenarios continue conventional scenario and building methodologies while seeking to add detailed analysis of social structural transformations in society in the transition to new sustainability.

Through detailed analysis of existing cases, Sondeijker proposed an original process for developing transition scenarios (TRANSCE), as shown in Table III-3 and Figure III-3. As can be seen here, transition scenarios point the way toward identifying the processes of system transformations to the desired future. Here, by repeatedly asking the following questions, the method gradually depicts the overall system transition.

- What are the images of a desirable future sustainable system? (Step 3)
- What are the necessary structural transformations to achieve the desirable future sustainable system? (Step 4)
- What are the barriers to structural change (Step 1) and drivers for structural change (Step 5)?
- What are the strategies that groups of actors could adopt (Step 6)?

In this way, the most important role of transition scenarios is to depict the form that structural transformation to a sustainable society should take, and identify the necessary strategies that should be adopted to achieve the transformation.

[67] With regard to considering 2050, the future in the long term, there are many challenges in the work of qualitatively describing the desired social vision and the pathway to achieve it. The future in the long term is greatly affected by many indeterminate macro and micro factors. As a result, the broader the field being examined, the greater the amount of data and analysis, leading to difficulties in rigorously treating the field. Especially when some individuals or an organization creates a scenario based on scarce data, they must take care to convince as many people as possible. Therefore, when developing a scenario, the process must be made transparent, so as to allow as wide a range of actors as possible to participate in discussions of data used and analysis presented, as well as of potential biases.

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

Table III-3 Stages in TRANSCE-based development of transition scenarios and their overviews[69]

#	TRANSCE Steps	Actions
1	**Barriers for structural change**	Defines currently ongoing and future-oriented problems that can be perceived as persistent.
2	**Transition challenge and scope of the system**	Breaks down the dominant regime along with its barriers for structural change. Carried out within a more long-term perspective of sustainability
3	**Images of a desirable future sustainable system**	The output of this step includes a distinguishing set of fully-fledged narratives of a future system state
4	**Necessary structural change**	Connects the persistent problems of the current unsustainable system (Step 1) to the stories of the future sustainable system (Step 3).
5	**Drivers for structural change**	Focuses on the interaction between drivers for structural change.' Entails the influences existing in the environment of the system under study
6	**Anticipative strategies of groups of actors**	Suggests, considers and selects potential new niches that can be employed for anticipating the drivers for structural change
7	**Framing the transition**	A coordinating step that ensures alignment and consistency between the previous steps altogether

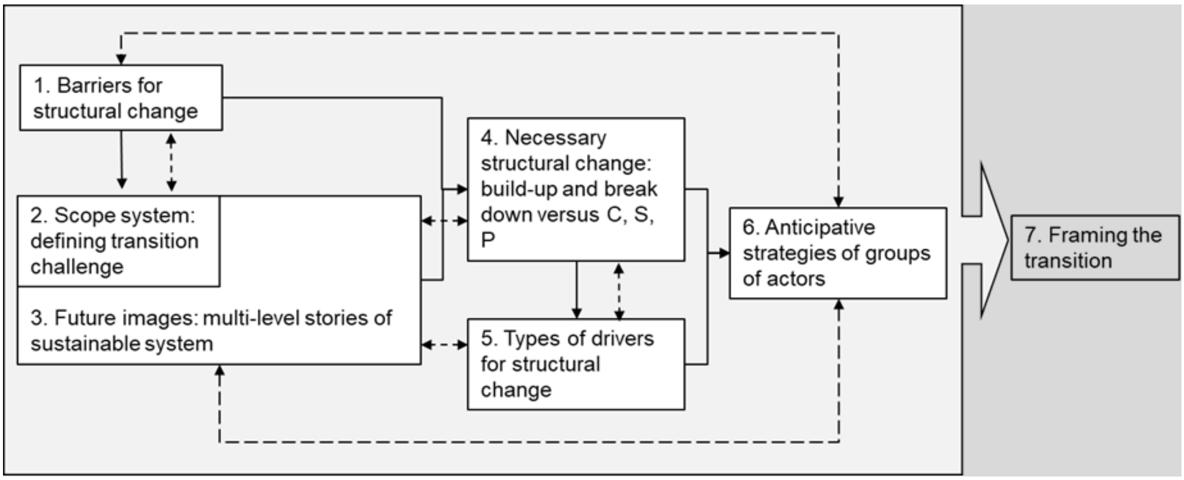

Figure III-3 Relationships between stages in TRANSCE scenario development[70]

[69] Saartje Sondeijker. 2009. *Imagining Sustainability: Methodological building blocks for transition scenarios.* Erasmus University Rotterdam. (http://hdl.handle.net/1765/17462)
[70] Sondeijker. 2009. *Imagining Sustainability,* p. 207.