Proposal

Toward Realizing Electricity Systems to Support Society 5.0

(Ver. 2)

April 17, 2019

Hitachi-UTokyo Laboratory

Introduction

In recent years, factors such as the mass deployment of renewable energy sources, expansion of information technology, advancements in globalization, and changes in peoples 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.

At the University of Tokyo (hereafter referred to as 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 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. 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. (hereafter referred as "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 H-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 is examining an energy system (particularly the electricity system) needed to underlie the data-driven Society 5.0. Given the inevitable transition from the conventional electricity system centered around a major power source to a new system that is decentralized, digitized, and that incorporates electrification/motorization and increased deployment of renewable energy, the laboratory aims to take into consideration domestic and foreign affairs to identify technical and policy/system issues pertaining to the future of the electricity system that will sustain Society 5.0. The laboratory intends to share these findings with stakeholders and publish them as recommendations.

Direction of Discussions

Discussions were carried out along three major axes with respect to the electricity system that will support Society 5.0.

A) Propose a vision for Society 5.0

The energy system should be redesigned on the premise that it will go beyond the conventional role of simply providing energy. Instead, it shall become instrumental to transforming society and individual lifestyles into something more closely aligned with the future. The energy system will continue to take advantage of Japan’s high reliability, technical ability, and human capital to strive for the establishment of Society 5.0, which will create new industries and jobs, while contributing its established vision and technology to the international community.

The discussions around the structural transformation of the industry must be broadly divided by scope: short-term, medium-term, and long-term. The transformation of energy structures will take time, given its extremely large impact on society and the scale of current infrastructural facilities. On the basis of this, we consider short-term scope to cover 5 to 10 years, medium-term scope to cover 10 to 20 years, and long-term scope to cover 20 to 100 years.

To strategically advance various measures amid countless uncertainties, we must formulate medium-to-long-term visions spanning to 2030, or even 2050 and beyond, and discuss what systems and policies (social systems) will be required to achieve these visions in different scenarios. In addition, it will be necessary to prepare technologically diverse options. Strategic investment will be needed from both a national and international standpoint given the high level of uncertainty in the development of the technology which will become important in mid-to-long-term scenarios, especially considering that these will not be ruled by market principles alone.

B) An open framework for social decision-making

For society to discuss and share its ideal form of energy system, 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. The aim will be to promote information-sharing among stakeholders, as well as the sharing of data and tools pertaining to energy systems, through cooperation among industry, academia, and the government. Such open debate will likewise encourage healthy competition among energy systems.

To form a social consensus on energy systems, we must look beyond present issues and come up with a process by which we can discuss the possibilities of future energy system from different perspectives.

C) Development of cross-functional human resources

To build an energy system that supports Society 5.0 and create an infrastructure industry that contributes social impact on a global scale, it is important to assess scientific and technological innovation, social systems, and economic mechanisms as a whole.

Industry, academia, and the government must work together to promote efforts beyond industrial, academic, and generational boundaries, and should develop human resources capable of discussing such multifaceted values.

Vision Formulation (for Society 5.0)	• Conduct discussions rooted in multiple scenarios and prepare diverse technological options to realize mid/long-term visions for 2030/2050. • 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 with established technologies.
An open social decision-making framework	• To share the vision of future energy systems, build an open platform to communicate and share quantitative and objective information, as well as a framework to make decisions rooted in this information. • Promote healthy competition among energy systems based on open discussion. • Share data and analytical tools as much as possible to form social consensus.
Training cross-functional human resources	• Train individuals capable of discussing multi-dimensional values, as the development of a new infrastructural industry will require an integrated understanding of scientific innovation, social systems, and economic mechanisms. • Develop initiatives that transcend industrial areas, academic disciplines, and generational boundaries through industry-academia-government cooperation.

Figure i: Direction of discussions

Main Points of Proposal Ver.1

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 that connects the local community will optimize the “3E + S"[1] 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 new technologies to facilitate a coordination mechanism that can integrate these distributed energy resources.

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 stabilization measures for the electricity system. They should create new services and businesses by establishing a mechanism to publicly share information among various infrastructural services, including not only the traditional services of electricity, gas, and water but also IT, transportation, and logistics.

To discuss the ideal form of the bulk power system, local communities should build a platform to evaluate the energy systems of the society as a whole, centered on electric power. Industry, academia, and government must collaborate to develop and share analytical tools and standard data. After considering the evaluation results, various stakeholders should discuss and form a consensus on the role of the bulk power system and invest in its transformation. In addition, they should incorporate and implement new control technology that digitally connects the bulk power system to the local community, and ultimately seek to share that technology and experience across the globe.

Pertinent systems and policies will be necessary to change the energy systems and embrace the challenges described above. In an era with numerous uncertainties in politics, the economy, and technological innovation, stakeholders should set the change factors which pose significant impacts to society as evaluation axes, and discuss systems and policies with multiple contexts. They should evaluate the outcomes of innovation and investment from multiple perspectives such as economic, environmental, and stability of supply, and implement PDCA (Plan, Do, Check, Act). They should globally expand the advanced energy systems built in Japan to contribute to the international community. Along with such policy and institutional discussions, it is also essential to consider practical aspects, such as investment for infrastructure export and security governance of the entire supply chain.

[1] Acronym of Economy, Environment, Energy Security, and Safety.

In addition, the development of energy systems requires strategic planning on multiple scopes (short-term, medium-term, and long-term). In particular, continuous investment will be needed to develop human resources and technologies. To foster the human resources capable of designing future energy systems from a broad perspective, that is, those capable of grasping science and technology, social systems, and economic mechanisms integrated into one entity, a system for cross-disciplinary research and training is needed. In such an avenue, studies of economics, financial engineering, and even sociology will be integrated with the areas of engineering, electric power, transportation, and information. In addition, the development of local communities and bulk power systems will be accelerated by proactively involving seasoned professionals, who are valuable assets.

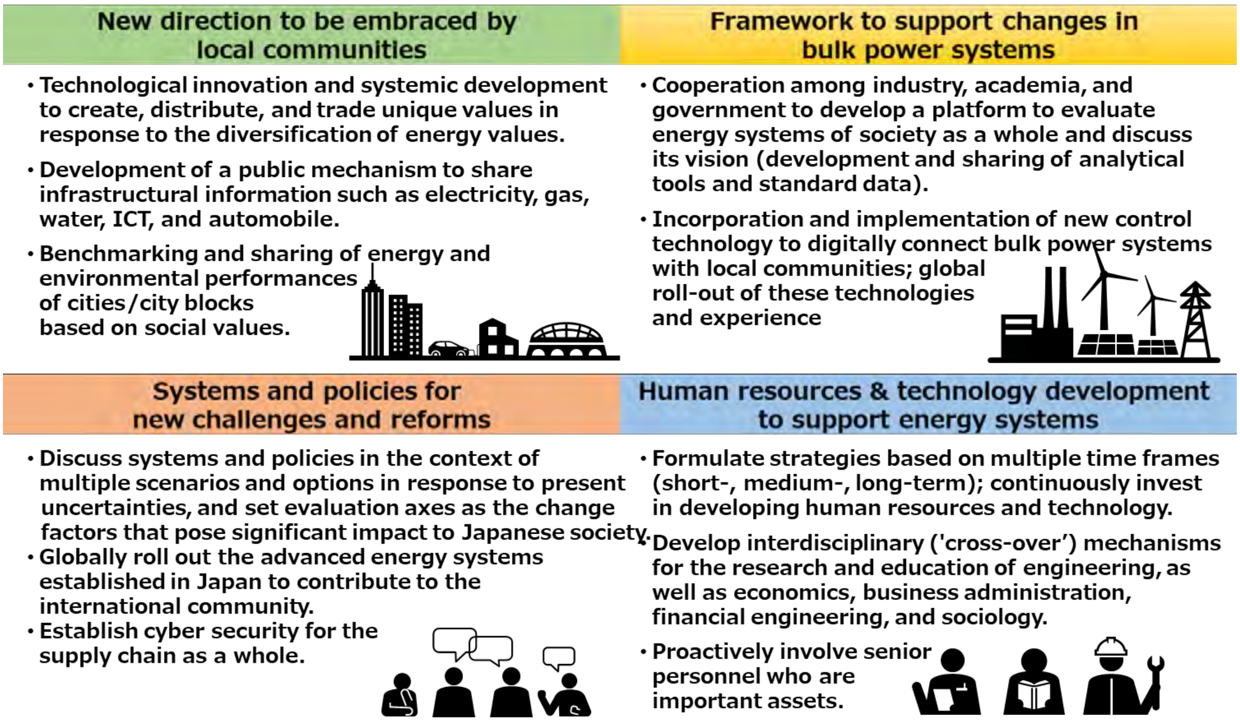

Figure ii: Discussion points for the realization of energy systems to support Society 5.0

Revised Aim and the Main Points of Proposal Ver. 2

Since publishing the first version of the proposal in April 2018, discussions on next-generation energy systems have taken place at various places. The review of the basic energy plan published in July describes the 2030 long-term energy supply-demand forecast (energy composition decided by METI in July 2015) and the scenario design for 2050. The review deems a multi-line scenario approach, which focuses on the latest information while setting ambitious goals, appropriate in an era as uncertain and unpredictable as the present. It states that it is necessary to introduce a scientific review mechanism for the selection and judgment of these scenarios. In addition, the blackout that occurred throughout Hokkaido following the Hokkaido Eastern Iburi earthquake in September 2018 reaffirmed the importance of resiliency. Against this landscape, the Ministry of Economy, Trade and Industry hosted the "Study group on the ideal energy platform utilizing next-generation technology" in October 2018 and subsequently formed the "Subcommittee on energy resilience for a decarbonized society" in February 2019. These have since helped advance discussions on systems and policies for next-generation energy systems, after consultations with various experts. In addition, these activities also reference studies by the H-UTokyo Lab.

Focusing on such discussions on the energy system and taking on a social perspective, the Cabinet Office published a proposal in April 2019 at the meeting on the "Long-term Growth Strategy under the Paris Agreement" (initially established in August 2018) for a long-term strategy to expand an economy and society with low emission of greenhouse gases. Furthermore, broad global discussions are expected at the G20 Ministerial Meeting on Energy Transitions and Global Environment for Sustainable Growth that is scheduled for June 2019.

H-UTokyo Lab has continued research amid the enlivening discussions on next-generation energy systems. Version 2 of the proposal aims to dig deeper into the topics covered in the first version, and specifically pursues the following two themes. The findings are appended to the first version of the proposal and summarized.

(1) Conceptual design of platform and data to evaluate the energy systems of society as a whole (mainly Chapter 5)

As mentioned above, discussions on the future energy system, taking into account multiple scenarios and numerous technology options, will require cooperation among industry, academia, and government to prepare the tools and data needed to analyze and evaluate the energy systems of society as a whole. In this section, we will conduct a conceptual design of the evaluation platform. We will assume and extract use cases in which various stakeholders utilize the evaluation platform and actualize the required specifications for analytical tools and standard data. In particular, we will define the required items per use case with respect to the information and data pertaining to power systems, power generation, demand, and outlooks, and study the scope of disclosure/information release. In addition, the focus will not only be on bulk power systems; we will also consider that the expanded charging infrastructure caused by the installation of distributed energy sources and mass introduction of EVs will also require changes in the electricity system (power distribution system) of local communities. An evaluation environment corresponding to this shall also be prepared. Moreover, the future energy system is premised on the coexistence of the bulk power system and the local community, and will evolve into a platform that can evaluate the level of cooperation between the two.

Information and data sharing will require anonymous processing and modeling, as well as the clarification of the scope of disclosure to protect individual privacy, national security, and business competition. There is also a need for mechanisms and frameworks to continuously develop this platform. Specific measures, such as the establishment and operation of neutral institutions, should likewise be discussed.

(2) Review of scenarios for next-generation energy systems (mainly Chapters 2 and 6)

We studied long-term scenarios for energy systems with a scope of 2050 and beyond. Our goal was to set the CO_2 emission reduction target outlined by the Paris Agreement given the major policy aimed at the decarbonization of society. We also referenced the two evaluation axes conceived by the H-UTokyo Lab: decarbonization (achieve 80% domestic reduction in CO_2 emissions, global reduction in carbon footprint using CO_2 credits) and decentralization (concentration of population near metropolises like Tokyo, Osaka, and distribution of medium-sized hubs due to regional revival and revitalization). We use these four scenarios to discuss technological and policy/institutional issues centered on electricity systems.

Table of Contents

Toward Realizing Electricity Systems to Support Society 5.0

Chapter 1: The Ideal Form of Future Energy Systems

1.1 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 humancentric, rich society, achieved by simultaneously growing the economy and solving social issues, using systems that seamlessly integrate cyber (virtual) and physical (real-world) spaces. In response to population increases, Society 4.0 (information society) emphasized efficiency improvements through scaling and was challenged by the homogenization of societal values caused by the uniformization of products, services, and processes. Other problems also became apparent, such as the unequal distribution of wealth and information (wealth–information concentration), vulnerability to natural disasters, and increases in environmental load. Society 5.0 will pursue resilience and sustainability by overcoming these challenges through technological innovation, allowing 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 new value (value creation), and regional and rural development.

Society 5.0 will construct energy systems characteristic of each regional community, with a focus on individual lifestyles. Amid the rapidly changing economic and societal landscapes and industrial structures, there will be increased collaboration and cooperation of the infrastructure services that support regional communities—which includes not only electricity, gas, and water but also ICT, transportation, and logistics—to rebuild energy systems suited to each regional community. Individuals will assess the utility value of energy beyond the conventional charge per energy unit, acknowledging its more diversified values such as environmental values (e.g., CO_2 emission reduction and the protection of regional resources) and values that reflect personal convenience and comfort. In addition to this progress, advancements will be made in the electrification and motorization of energy consumption and the popularization of the power electronic technologies that underlie electrical power use; society will begin using new types of secondary energy that can be stored in large volumes for long periods of time. Compared to the past, advances in digitization have made energy consumption more flexible with respect to time and volume, with a higher degree of freedom. Data play an important role in driving the demand for this new approach to energy with enhanced controllability. The world will transform into a place where energy supplied to consumers will be integrated with new value and services (Figure 1).

Chapter 2 describes the results of examining the long-term scenario of Japans energy system from H -UTokyo Lab's unique perspective. We take into account the 2050 CO_2 emission reduction target set by the Paris Climate Agreement to discuss the technological and systemic/policy issues pertaining to the electricity system. We base the discussions on the four scenarios, composed of two uncertainty elements, decarbonization and population decentralization, which we use as evaluation axes. Note that these scenarios are influenced by the uncertainty of medium-to-long-term social and technological trends, and thus we do not select specific scenarios as policy targets.

As local communities transform, the electricity system must adapt and undergo major reforms. Conventionally, large-scale power sources were featured as the main force to provide universal service to the entire country. The service was nearly uniform geographically and temporally, and was offered as a fixed rate system. In the future, it will be more difficult to expect uniform values with respect to energy supply and utilization amid increasing deployment of distributed energy resources, such as renewable energy (hereafter referred to as RE), and in particular, variable renewable energy (hereafter referred as VRE), such as solar power generation and wind power generation, whose output fluctuates according to weather conditions. The value of energy is measured by energy *amount*, or kWh value, along with adjusting capacity, a value that supports the energy *quality* for the entire system. The latter includes kW, or the contribution to the capacity required by the entire electricity system (supply capacity), and ΔkW, the supply-demand adjusting capacity to short-term fluctuations. Chapter 3 details these new endeavors of local communities from a technical perspective, while Chapter 6 tackles the same from an institutional and policy perspective.

Bulk power systems will play an important role in optimizing the 3E+S of the entire society amid the transformation of energy systems in local communities, particularly power systems. It is impossible for a single local community to deal with the uneven geographical and temporal distribution of renewable energy by shutting off interaction between energy supply-demand and values. Thus, the bulk power system fulfills the role of connecting multiple local communities and coordinating the whole system. To improve the benefits for society as a whole, it is necessary to strategically transform the bulk power system based on the geographical distribution and temporal fluctuations in demand, supply, and distribution networks.

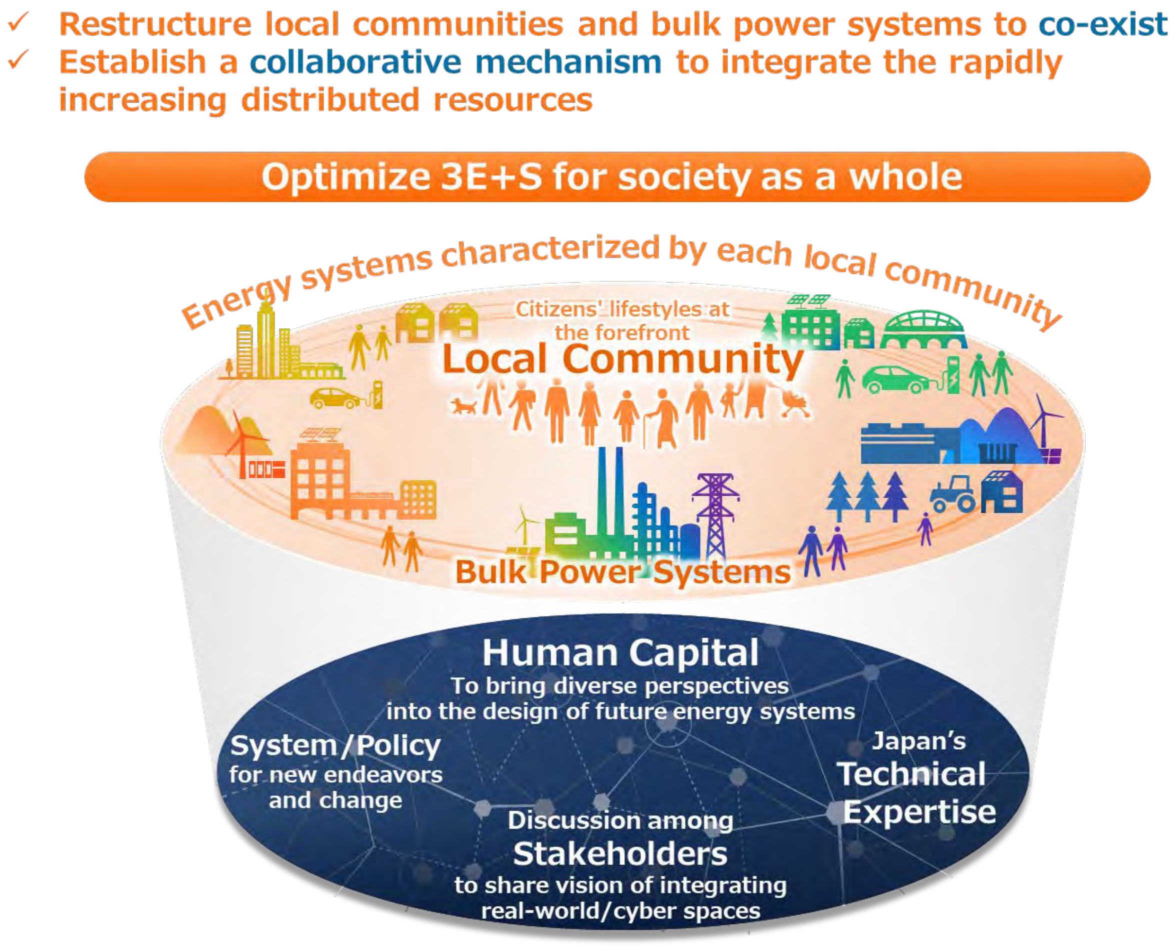

Figure 1: An overview of the energy system that will support Society 5.0

Under such circumstances, the roles of the local community's energy system and the bulk power system cease to be uniform; thus, it is necessary to reconstruct these systems on the premise of coexistence. Currently, the bulk power system is responsible for controlling the entire electricity system. In the future, the number of communities with distinctive energy systems (formed by the inclusion of renewable energy and decentralized energy resources) will increase further. In turn, the bulk power system will also utilize the adjusting capacity supplied by local communities to realize a world with optimized 3E+S. As energy systems distinctively built for each local community, it will become important to discuss systems and policies (social systems) as one means to achieve role-sharing with the bulk power system. Chapter 4 and Chapter 6 describe the technical aspects and the institutional and policy aspects, respectively, of initiatives to reform bulk power systems.

In addition, such future energy systems will require novel technology to create a new cooperation mechanism integrating distributed energy resources (DER), due to the increase in factors that require coordination and adjustment: the decentralization of power sources, coordination of bulk power systems with multiple local communities, and linkage of human behavior. Currently, there are several initiatives for the utilization of DER, such as VPP[2] and resource aggregation[3], but it is clear that other factors requiring mutual coordination will increase exponentially in the future. Unlike conventional bulk power systems that target large-scale power sources, the integrated control of diverse DER, possessing an extremely large number of uncertainties, will be a major challenge in the development of advanced technology, such as the combination of autonomous distributed control and centralized control. From a systemic perspective, it is necessary to facilitate data sharing across the entire energy system, construct a world that merges the physical and cyber space, and conduct repeated discussions with various stakeholders. It is important for stakeholders to be able to discuss on equal footing; the national government should promote the creation of such an environment by encouraging the sharing of analytical tools and data. For example, although most renewable energy has basically zero fuel cost, measures will be needed to maintain the quality and stability of a mass-deployed electricity system. At par with the importance of cost minimization for the entire society is an evaluation platform that can be used to gain social consensus through visualization and by eliciting shared understanding. Data sharing is premised for this purpose. Chapters 3 and 4 discuss the technical aspects of such initiatives that connect local communities to bulk power systems. Chapter 5 discusses the conceptual design and materialization of the evaluation platform, while Chapter 6 details the initiatives from a systemic and policy angle.

To date, Japans electricity system has maintained a high level of reliability. Japan possesses superior technology and human resources to support these systems. Thus, Japan should use these strengths to create the ideal energy system. Chapter 7 details the utilization of human resources.

1.2 Changes in Japans Electricity System and Present Challenges

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.

[2] Virtual Power Plant (VPP) is the integrated management of grid-connected units (as if large power plant) using technology to aggregate distributed energy resources (DER) such as power generation, storage, and demand management.

[3] Resource aggregation: an integrated control mechanism similar to VPP that uses technology to connect decentralized energy resources.

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, and further weeding out of businesses from overhauls in the electricity system. This trend may be exacerbated by the separation of electric power production and supply scheduled for 2020. As a result, it may become difficult to transform the energy sector to Society 5.0 because of delays in the following: appropriate renovations of aging facilities, coordination with ever-increasing distributed energy resources, and handling shifts in the form of energy consumption caused by digitization. Stakeholders will need to depict a long-term scenario for future energy systems based on an assumption of uncertainty, clarify necessary technologies and investment targets, and then discuss and construct policies and systems to secure investment.

1.3 A Phased Approach for the Medium-to-Long Term

Discussions from diverse perspectives are necessary to realize the vision described thus far. In a world with increasing uncertainty, the strategic implementation of varied initiatives should entail the formulation of medium- and long-term goals towards 2030 and 2050, along with discussions of systems and policies to achieve these visions in multiple scenarios. In addition, a range of technology options must be prepared.

The deployment of renewable energy, a primary power source, is a key driver of change when considering technology options. Given the significant impact of Variable Renewable Energy (VRE) on the electricity system, it will be necessary to prepare phased initiatives corresponding to increases in the rate of deployed VRE. For example, the International Energy Agency (IEA) has proposed steps to deploy measures in accordance with the ratio of VRE to the overall generated power; they also expect issues related to economic efficiency and the stable operation of the power system to occur in different stages. To respond to such issues, IEA points out that it is necessary for all segments—from power generation, transmission, distribution, and consumption—to have the flexibility to adjust for the supply-demand balance (Figure 2). In addition, a surplus inevitably occurs when VRE exceeds 50% of the total generated energy. Other measures like the electrification of heat, transportation, and P2G (power-to-gas) or means to store the temporary imbalance between generated VRE and demand will also become necessary. In addition, gaining flexibility (adjusting capacity) not only from conventional large-scale power sources but also from decentralized power sources, energy storage, and consumers will necessitate new initiatives, such as the establishment of a coordination mechanism and strategic assignment of grid codes[4] pertaining to these distributed energy resources.

Technological progress related to energy storage and stockpiling will also need to be prepared in the context of multiple scenarios. The phased development of large-volume and long-term energy storage will be necessary for various power supplies, including renewable energy, to meet demands, while still being within the constraints of low carbon emissions. In addition to energy storage, new types of secondary energy that are capable of storing/stockpiling at a similar scale as oil has traditionally been capable of will likewise be needed. Regarding these secondary energy sources, it is imperative to anticipate production, storage, and timely utilization, in order to plan and introduce the production and storage facilities, transportation infrastructure, and utilization technologies in time for actual utilization.

Technology development imperative to these medium-to-long-term scenarios cannot be realized solely through market forces; rather, it requires continuous investment from a national perspective. In Chapter 6, we will discuss the implementation framework in detail from a system and policy perspective.

[4] Grid Code: technical specifications for electric networks (in this instance, refers to the specifications for the interconnection of distributed energy resources (DER) and electric networks.)

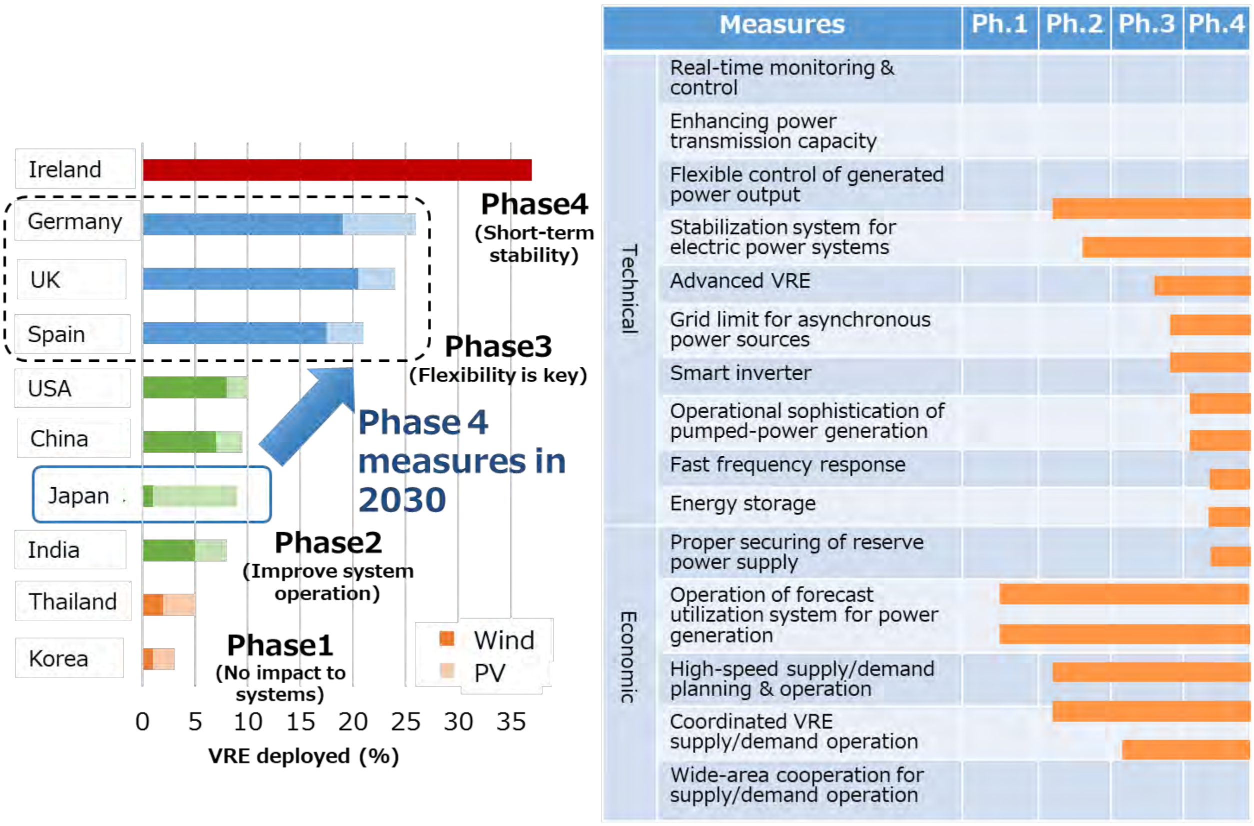

Figure 2: Deployed VRE amount and measures for power system operation

(Prepared on the basis of a report by the International Energy Agency (IEA)[5])

[5] IEA, "Integrating variable renewables: Implications for energy resilience," Asia Clean Energy Forum 2017

Chapter 2: Consideration of Long-Term Energy Scenarios

Amid mounting mid-to-long-term uncertainties caused by global economic and social changes and technological innovations, it is important to assume multiple long-term energy scenarios to realize Society 5.0. Technology development and facility deployment to the energy infrastructure must be considered in units 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.

2.1 Multiple System and Policy Options: What is Scenario Analysis?

Changes in the global energy resource landscape, diversification of global market players, and technological innovations such as EVs, storage batteries, and hydrogen applications have caused uncertainty to rise in various dimensions such as politics, economy, and technology. Such background calls for flexible decision-making that matches the respective conditions and future outlooks; thus, it is important to first conduct a scenario analysis that visualizes multiple future scenarios. Scenario analysis explores multiple possibilities rather than a single forecast and designs energy systems and strategies for each scenario.

2.2 Long-Term Energy Scenarios for Japan Proposed by H-UTokyo Lab

In this section, we discuss several scenarios to achieve the goals of the Paris Agreement—an 80% reduction in CO_2 emissions by 2050—by applying the change factors with high uncertainty and that have a major impact on Japanese society as evaluation axes.

(1) Four Long-Term Energy Scenarios

We assumed four scenarios using the following two items of large uncertainty as evaluation axes: "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) (Figure 3). The reasons for selecting the evaluation axes and specific details are described below.

Japan, a resource-poor but technologically established country, must develop and deploy technology to meet an increasingly decarbonized world, and reconcile eco-friendliness with economic growth as these technologies expand overseas. However, it will take a considerable amount of time to clear the high hurdle of technological innovation while balancing it with profitability. Therefore, a realistic solution may be to use CO_2 credits in the meantime and thereafter meet environmental criteria from a global perspective, rather than strictly adhering to domestically achieving the 80% reduction target for CO_2 emissions. In addition to technological aspects, we also envision factors like maintaining international cooperation for decarbonization and geopolitical uncertainty. Therefore, we selected "decarbonization" as an evaluation axis (horizontal axis). In Figure 3, the two scenarios on the right reflect those that achieve domestic CO_2 reduction targets; in these scenarios, there will be enhanced technology options for decarbonization, such as increased electrification, hydrogen applications, cost reductions for storage batteries, and proliferation of EVs and CCUS[6]. On the other hand, the two scenarios on the left represent cases where the decarbonization technologies described above have limited development and proliferation; these scenarios achieve overall CO_2 reduction targets with overseas contribution, from the perspective of equalizing marginal abatement costs for CO_2.

Decentralization of population and industry through regional revival/revitalization equates to the decentralization of energy demand and greatly impacts the energy system. As Figure 4 shows, more than half of the Japanese cities will have their population halved by 2045 if measures are not implemented on a national level. In 2014, MLIT announced their Grand Design 2050[7] as a plan to develop the social infrastructure of national land in response to population decline and massive disasters. The main focus is to develop a safe living environment that can respond to huge disasters, while maintaining the autonomy of local cities. The design uses the keywords "compact + network" to address population decline; it aims to form land that promotes exchange by using information communication technology, such as the Internet, to interlink various functions. MLIT plans to create a "union of higher-order regional cities" whereby neighboring cities can work together across prefectural boundaries. It aims to form and maintain 60-70 regional hub cities nationwide, each consisting of a population of over 300,000 (Figure 4). On the other hand, the success of this idea is impacted not only by policies related to land use but also by the economic activities of companies and individual lifestyles. Thus, continuation of the current trend is possible: that is, population concentration around major cities, such as Tokyo and Osaka. It is said that China is also becoming more polarized between cities with population concentration and cities with shrinking population. Thus, we consider "population

[6] CCUS: Carbon Capture, Utilization and Storage
[7] http://www.mlit.go.jp/kokudoseisaku/kokudoseisaku_tk3_000043.html

decentralization" as an evaluation axis. In Figure 3, the upper two scenarios are those with progressing regional revival/revitalization; this scenario shows progressing decentralization of the population and industry while avoiding the erratic scattering of population. With regard to energy systems, regional revitalization is driven by the deployment of various distributed power sources to the local community; renewable energy sources play a particularly important role.

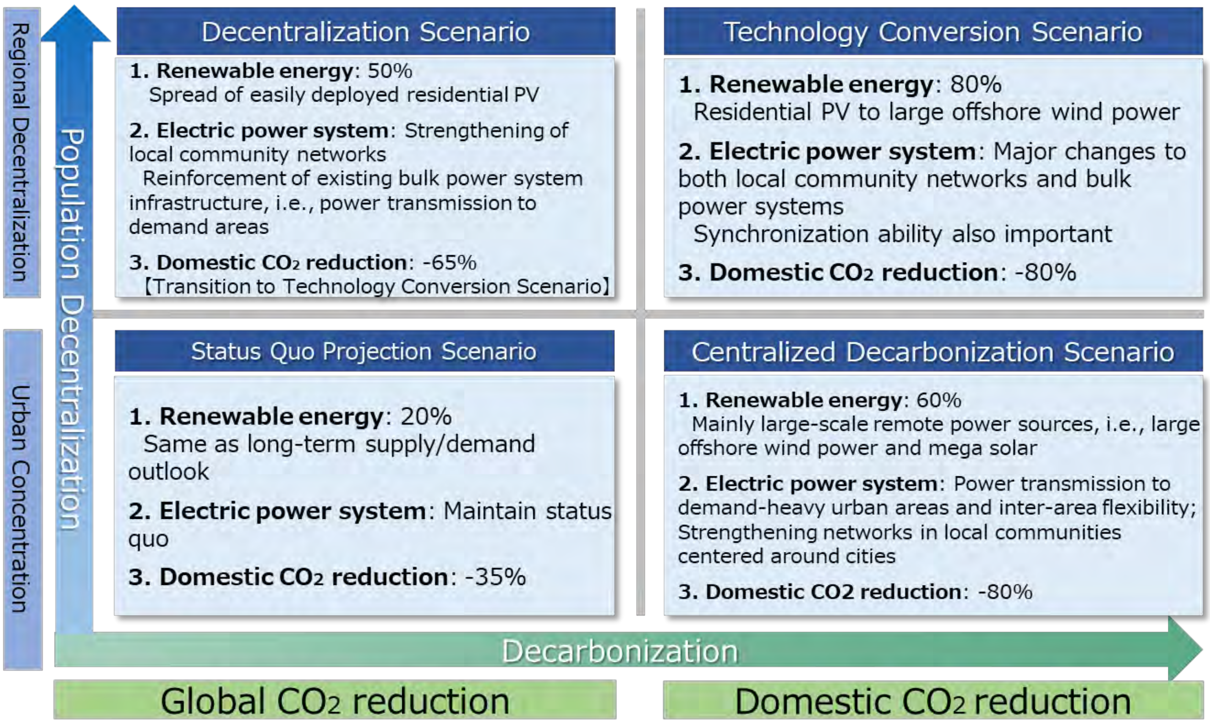

Figure 3: Considerations of Long-Term Energy Scenarios in Japan

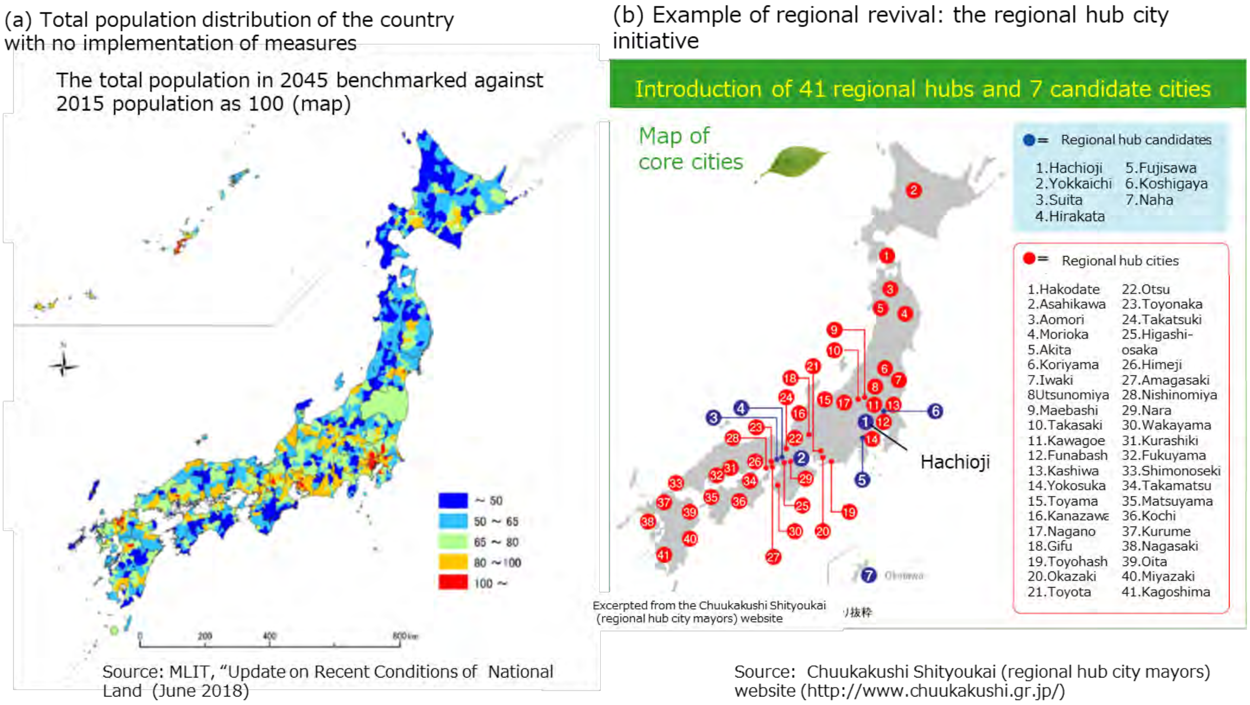

Figure 4: Nationwide population distribution and formation of regional hub cities in 2045

The "status quo projection scenario" depicts a case where international contribution becomes the primary driver of reductions in CO_2 emissions due to sluggish deployment/operation of decarbonized energy sources (renewable energy, nuclear power)[8] and stalled development of decarbonization technologies such as CCUS. In addition, the scenario depicts stagnation in regional revival/revitalization with concentration of population and industry to areas proximate to large cities. The energy supply is in line with the long-term supply-demand outlook of the Basic Energy Plan, which denotes the primary use of large-scale concentrated power source; no major changes are made to either electricity systems in local communities or bulk power systems.

The decentralized scenario features advancements in regional revival/revitalization, as well as a shift to a decentralized type of energy supply distributed closer to demand areas. There will be increased deployment of microgrids and VPPs, and the energy system will transform into one where the local community plays a leading role. However, VRE deployment will be suppressed to about 30% because of economics and limitations with connecting to the power system. Furthermore, in this scenario, the development and proliferation of decarbonization technology will still be premature; international contribution will be the primary driver of CO_2 reduction. We could say that the decentralized scenario is a transition period towards the technology conversion scenario to be described later on.

[8] We assume the same level of renewable energy as METIs long -term outlook for energy supply and demand (2030).

In the centralized decarbonization scenario, advances in the development and proliferation of decarbonization technology helps achieve domestic reduction of CO_2 emission. Large-scale, concentrated types of energy supply are economically suited to this scenario, since the population and industry are concentrated in the suburbs of major cities. Renewable energy, such as mega solar and offshore wind farms, is also suitable. The bulk power system is fortified to optimize inter-area flexibility and wide-area operation. In rural cities, existing facilities will be maintained in a logical form as electricity demand will decrease with the shrinking population. However, in areas suited for renewable energy, the electrical distribution network will be fortified to optimize energy use.

The technology conversion scenario assumes continued decentralization of population and industry. The energy supply will be centered on decentralized power sources located near demand areas. The scenario will embrace the concept of managing urban networks such as the union of higher-order regional cities. The scenario aims to achieve CO_2 emission reduction targets domestically and primarily through renewable energy, and assumes a deployment of about 80% (VRE ~60%). Technological innovations in energy storage, such as electricity storage, heat storage, and hydrogen, will be indispensable to maintaining the supply-demand balance. The direction of the electricity system will revolve around the establishment of bulk power systems primarily in Tokyo, Osaka, and other major cities, and the expansion of electric distribution systems in independent local communities. With respect to energy transmission capacity, society will move towards balancing bulk power systems and local communities. However, system stability issues, such as lack of synchronization, should be solved with VRE deployment as a majority.

The examination of these four scenarios reveals that the electricity system can change because of advancements in decarbonization technology and regional revival/revitalization. We should note these scenarios should flexibly adapt to influences from medium-to-long-term social and technological trends, with no one specific scenario being set as a policy target.

(2) Sample Quantitative Analysis for the Technology Conversion Scenario

Below, we focus on the "technology conversion scenario" and quantitatively evaluate the energy system in this scenario. Figure 5 depicts an overview of the findings.

In this evaluation, we applied the technology selection model developed by the Fujii-Komiyama Laboratory at the University of Tokyo. 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 targets and upper limits to the deployment of power generation equipment. In this section, we examine the technologies that comprise the energy systems of the "technology conversion scenario" with the precondition of an 80% reduction in CO_2 emissions in 2050, as compared to 2013.

According to the technology selection model, the decarbonization of the energy sources, progresses in electrification, and optimization of energy use must occur simultaneously to meet CO_2 reduction targets. Appendix 1 shows the details of the calculations. VREs such as wind and solar power will be deployed and expanded as an energy source primarily among local communities, accounting for 60% of power generation. When combined with hydropower, biomass, and others, the deployed renewable energy 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 1.46 trillion kWh (45% electrification rate) from 1.0 trillion kWh in 2013.[9] In such a scenario, investments in next-generation energy systems will be funded by growing demand; economic growth and decarbonization will grow hand-in-hand through a positive cycle of growth and investment.

In addition, the maximum electrification case cited in "Utility 3.0" (case study results publicly available)[10] assumes 55% renewable energy ratio[11] and 70% electrification rate (100% for the consumer sector) to achieve 72% CO_2 emissions in 2050. On the other hand, the technology selection model further increases the renewable energy ratio (77%), while easing the electrification rate (45%).

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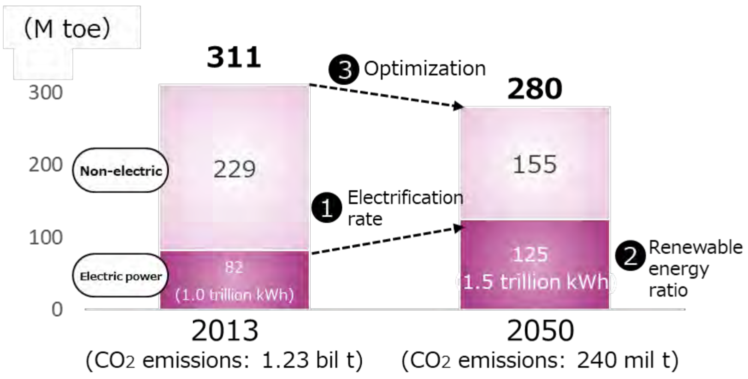
[9] Electrification of industrial sectors centered around heat sources (increased use of electric furnaces, at 150x in 2050 (vs 2030)) and household sectors (deployment of high-efficiency heat pumps in the business sector increased by 1.8 times by 2050), as well as acceleration in electric vehicle adoption.

[10] Case study in "Energy Sangyo No 2050 Nen Utility 3.0 He No Game Change (Transition of the Energy Industry to Utility 3.0 by 2050)" (Nikkei Publishing)

[11] We assume 65% from renewable energy + nuclear power, of which nuclear power made up about 10%.



Energy supply/demand (vs 2013)

1. Electrification ratio: 26% → 45%
2. Renewable energy ratio: 14% → 77% (VRE 60%)
3. Optimization: -10%

3E status (vs 2013)

Environment: -80% CO2 emissions
Economy: Balance decarbonization and economic growth
Energy Security: status quo (self-sufficiency ratio 6% → 45%)

Electrification	2013	2050	Approach
Energy demand	1.0T kWh	1.46T kWh	ZEV and heat pump expansion
Total demand	311 M toe	280 M toe	Population decrease, optimization through digital technology.

Power generation composition	2013	2050	Details
Renewable energy	14%	**77% (VRE60)**	PV: 20% Wind: 40%
Other	86%	23%	LNG, nuclear, etc.
Total	100%	100%	

Figure 5: Analysis of energy supply-demand in 2050 (technology conversion scenario)

Figure 6 shows the relationship between the reduction in CO_2 emissions and energy consumption. The energy consumption forms a moderate upward curve in response to CO_2 reduction, and rises sharply around 60%. Therefore, we believe that the following innovations will be needed to achieve significant CO_2 reduction in an economically efficient way (such innovations will achieve features indicated by the dotted line in Figure 6, “Relationship between CO_2 emissions reduction and electric energy consumption”).

- On the supply side, we expect reduced costs for decarbonized energy sources (renewable energy, nuclear power, etc.) and cost reduction and development of new technology for energy storage to accommodate adjustments in renewable energy.
- On the demand side, we expect optimization and cost reduction in electric heat source devices (electric furnaces for various industries, heat pumps, etc.) to promote deployment.

Thus, simulations enable social decision-making with objective basis. As we show in Section 6.1, it will become necessary to upgrade the methods for scenario analysis in the future to better detail the energy systems for each scenario.

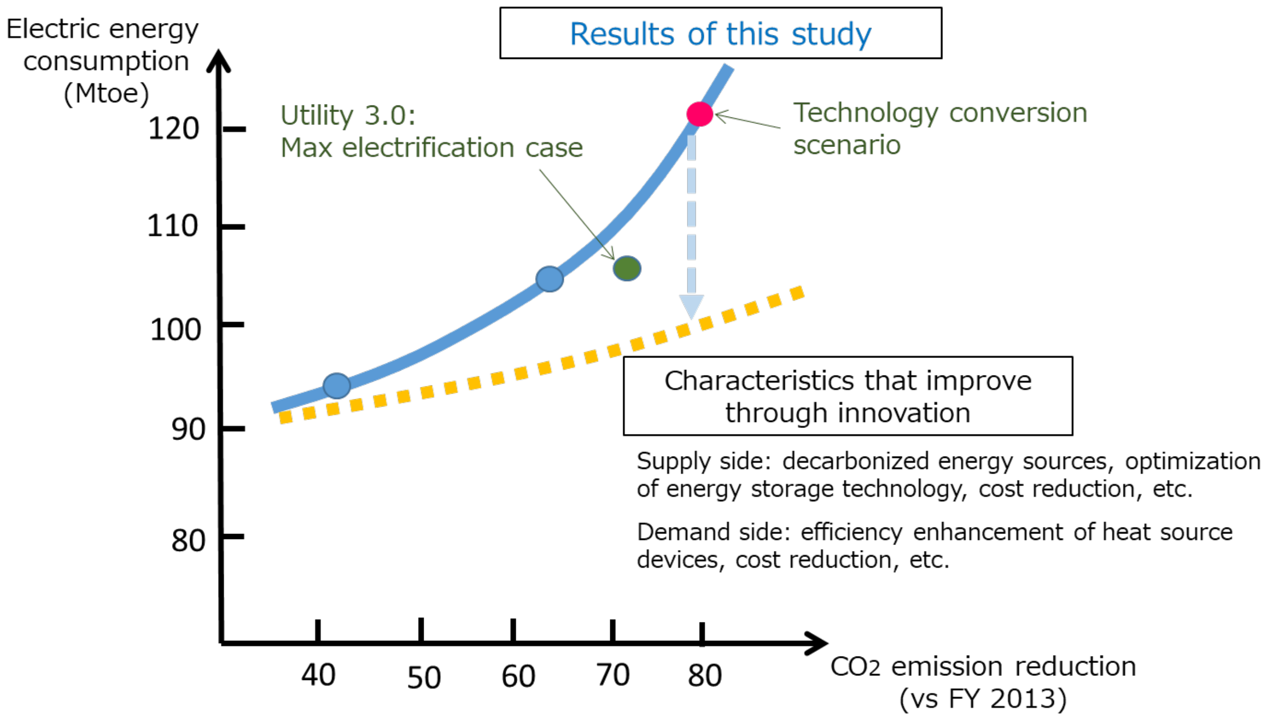


Figure 6: Relationship between CO_2 emissions reduction and electric energy consumption

Chapter 3: New Direction of Challenges to be Addressed by Local Communities

3.1 Overhauling the Local Community

As we described in Section 1.1, individual lifestyles will take center stage as Society 5.0 develops energy systems unique to each local community. Society 5.0 must view the local community from various perspectives (local government, city blocks, community) and create a framework in which not only electricity, gas, and water but also ICT, transport, logistics, and other social infrastructure will be integrated to support the lives of individuals. Energy values will diversify into those pertaining to environmental sustainability (CO_2 reduction and conservation of local resources), as well as convenience and comfort in daily life. Amid a shift from energy consumption to service utilization, Society 5.0 will realize a system for energy generation and distribution that meets the service quality required by the respective communities.

Furthermore, as the ratio of VRE and other distributed energy sources increases, the value of electric energy will be represented not only by kWh, or the "amount" of electricity, but will count also on flexibility values to support the energy "quality" of the power system as a whole; these include kW, which reflects the contributions to the capacity needed by the entire electricity system (supply capacity), and ΔkW, which reflects its capacity for supply-demand adjustments in response to short-term changes. Society 5.0 must incorporate infrastructure and systems that distribute and trade these new values.

An example of unique energy values built for each local community are areas suited for renewable energy that extend beyond stabilization measures of electrical systems, to the utilization of local resources (including renewable energy) to grow local industries. As the cost of generating renewable energy declines and approaches grid parity,[12] Society 5.0 will strive to proactively utilize excess electricity where marginal cost per kWh is close to zero, and create industries through the use of new local sources of energy. Some initiatives under consideration include the review of legal systems and rules (including the Electricity Business Act) that assume unilateral power supply from bulk power systems to areas of consumption, and the realization of bilateral distribution that actualizes local energy supply-demand.[13]

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[12] Grid parity occurs when a renewable energy source such as solar can generate power at less than or equal to the price of power from the existing commercial electricity grid.

[13] METI Energy Research Group, 4th subcommittee on the mass deployment of renewable energy and next-

Regional hub cities should strategically strengthen their energy resiliency. To elevate international competitiveness, these cities must furnish an appealing environment to global companies who seek a business continuity plan (BCP). Conventionally, various legal policies and rules have been established for the responsibility of power transmission/distribution operators to energy security and the obligation of retail operators to ensure supply capacity, in order to manage the quality of electricity and provide uniform and versatile services. We believe that, to realize resiliency and other values, it will be desirable to review these legal policies and rules and proceed with adequate deregulation to allow energy operators in local communities to implement the necessary initiatives.

These reforms will necessitate technological innovation and systemic improvements that will allow local communities to create, distribute, and trade unique values (Figure 7). The revitalization of the energy supply business in local communities will require the deregulation of legal systems and rules related to wheeling and connection fees, while introducing new roles to DER, such as continuous operation (FRT requirement) to achieve resiliency. On the other hand, local communities will need to re-establish the regulations necessary to maintain social benefits. The prerequisites to this revitalization are energy-saving and low-carbon behaviors in the household, business, industry, and transportation sectors. Electrification and motorization will accelerate in various areas and applications, such as in the provision of heating/cooling by heat pumps, electric vehicles (EVs), fuel-cell vehicles utilizing hydrogen, and enhanced heat utilization in the industrial sector. Innovation of new technologies, such as medium-to-high-temperature heat pumps, wireless charging, energy storage, and smart inverters[14] will be necessary to integrate distributed energy resources (DER) into electricity systems, as utilization continues to ramp up in power electronics and secondary energy sources capable of large-volume, long-term storage. We describe such initiatives in Section 3.2. Furthermore, the social implementation of these initiatives will necessitate data sharing among various types of infrastructures, as well as the benchmarking and sharing of evaluation methods for local communities' energy and environmental performance. We describe these approaches in Section 3.4.

generation electric networks, document no.4 (March 22, 2018)

[14] Smart inverters provide diverse system services corresponding to the state of the electric network through autonomous or remote control.
Power conversion system commonly used for photovoltaic (PV), electricity storage, heat pump, etc. Synonymous with Smart PCS (Power Conditioning System).

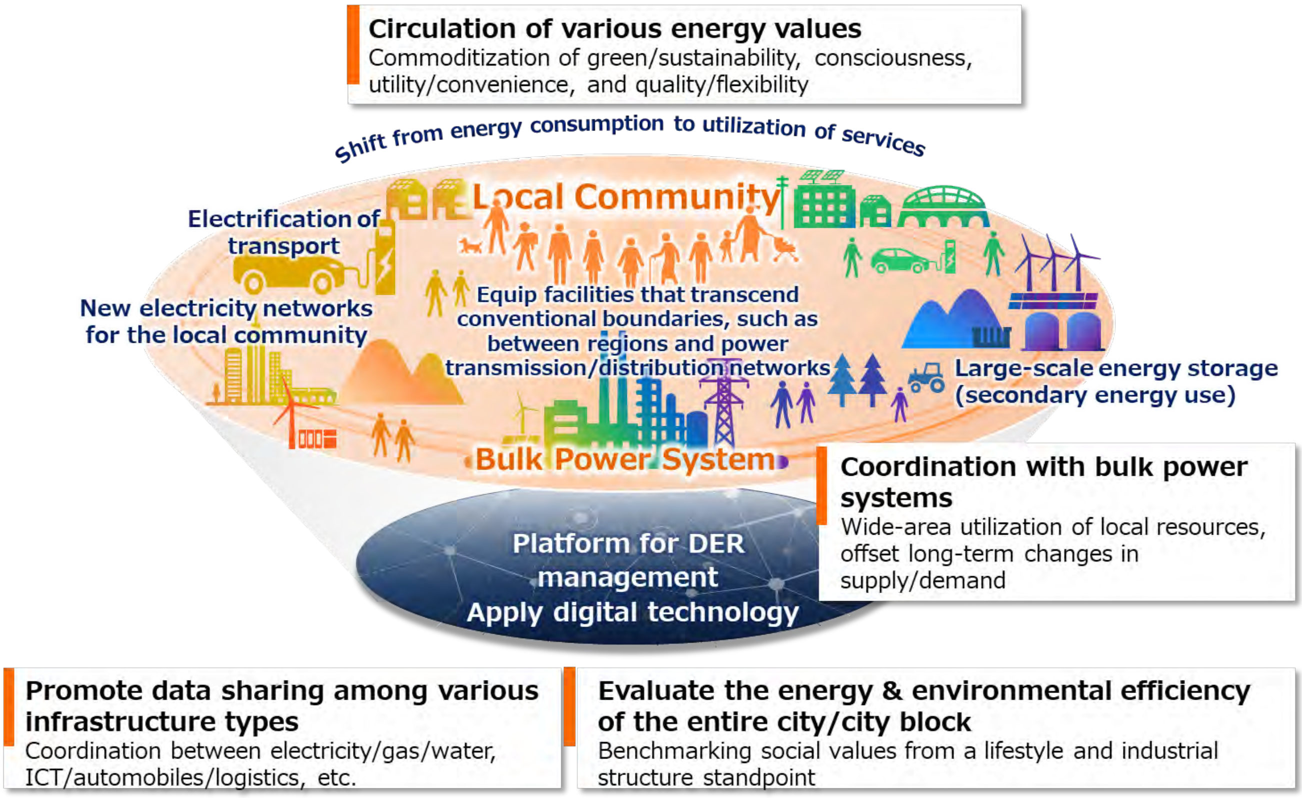


Figure 7: Changes in local communities' energy systems

3.2 Technological Initiatives Towards a Distribution of Diverse Energy Values

In response to VRE output fluctuations, it will become necessary to supply adjusting capacity in various time domains. In addition to conventional, large-scale power sources such as thermal, hydropower, and pumped-storage hydropower, we expect contributions from distributed energy sources such as VRE, demand from EV charging and heat pump hot water supply, and distributed storage like storage batteries. The adjusting capacity afforded by these distributed energy resources (DER) will apply to more targets and will be realized by dynamic retail pricing synchronized to VRE output fluctuations, along with the autonomous management of demand, based on these factors. Retail pricing information and demand control signals are calculated and distributed in the operational plan of the entire electricity system, based on market transaction results, and are reflected in real time (Figure 8). In addition to centralized power systems, system operations may be shared by aggregators that manage a large volume of demand. To achieve this new form of supply-demand management, the community will require not only the development of technology related to equipment use but also digital technology infrastructure to manage DER, the operation of electricity systems using this infrastructure, and the formation of a system that includes market operation.

DER management in local communities will contribute to the stable and economically efficient operation of the power system through its ability to adjust supply-demand and voltage in various time domains; nevertheless, this should not come at the sacrifice of comfort, such as the thermal environment and mobile services. Therefore, it will be necessary to understand and analyze the service demands of homes and businesses and evaluate various forms of energy consumption. Various technologies are disseminated on the basis of constraints (grid code in the case of power, etc.) and review of equipment formation. To establish new technologies for operation, it will be necessary to develop a shared platform for evaluation, including large-volume analysis of demand characteristics, retail pricing, and remote control response analysis based on these characteristics, and the analysis and evaluation of plans for aggregator operation (See Chapter 5).

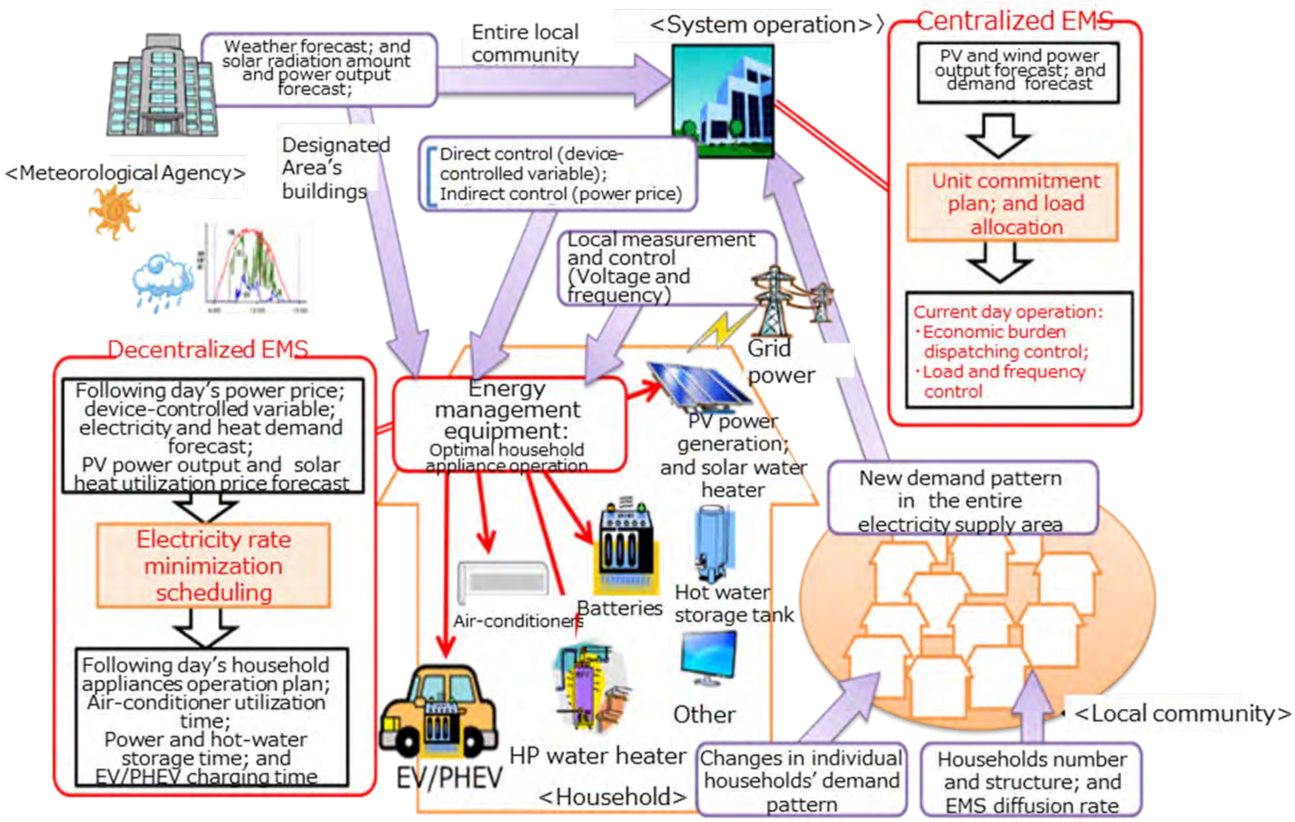


Figure 8: Utilization of autonomous management and remote control of a local community's distributed energy resources (DER) to provide services

(Source: paper presented at the annual conference of power and energy society, IEEJ by Ogimoto Laboratory, The University of Tokyo[15])

[15] Ogimoto, K., Iwafune, Y., Kataoka, K., Ikegami, T., and Yagita, Y. (2011). Cooperation Model of Centralized and Decentralized Energy Management for the Supply Demand Adjustment in a Power System, Proceeding of Power and Energy Society Conference of Institute of Electrical Engineers of Japan, I-16

The case study “The Japan-US Collaborative Smart Grid Demonstration Project in Maui Island of Hawaii State” conducted by New Energy and Industrial Technology Development Organization (referred hereafter as NEDO) demonstrated technologies that use various DER to handle abrupt supply-demand imbalances such as the duck curve[16] in solar power generation, or unexpected deviations in wind power generation caused by strong wind (Figure 9). While this study confirmed the provision of adjusting capacity (flexibility), a value that had long been lost in local communities, we must also note that such social experiments are limited in scope and do not extend beyond demonstration.

Given the exponential increase in distributed energy resources (DER), communities will need to develop new technologies to create a coordinated mechanism that integrates these. We will also discuss the possibility of P2P trading[17] using block chain. With respect to a mechanism to utilize various DER, it is also important to accelerate the creation of a new collaborative mechanism by first establishing a system/policy through the cooperation of industry, academia, and government, and then promoting social implementation by greatly enhancing the scale and number of demonstrations.

[16] Duck curve is the phenomenon in which daytime solar photovoltaic power production depresses the appeared demand, while demand sharply increases in the evening when the solar power generation stops.

[17] Peer-to-peer (P2P) energy trading: In this case, direct trading between multiple energy companies and consumers (including prosumers)

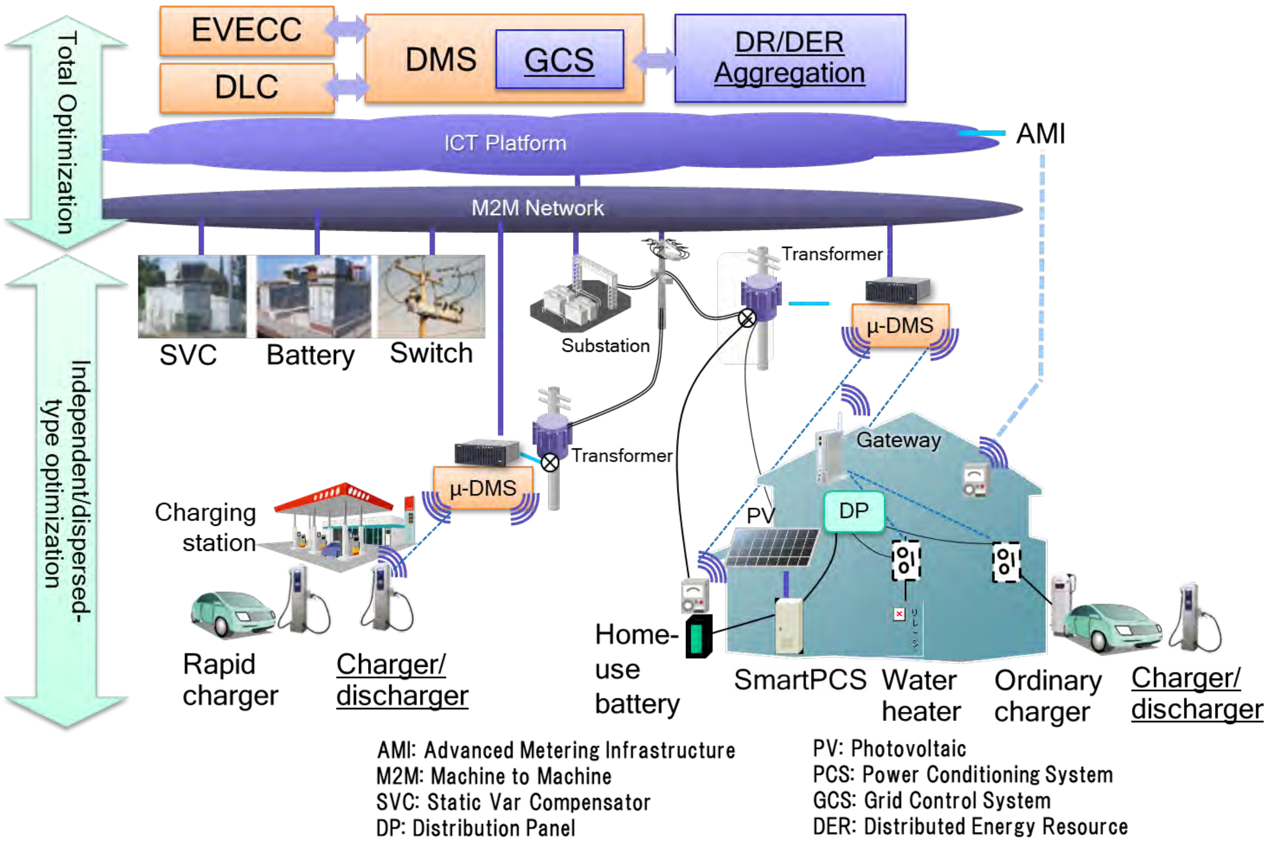
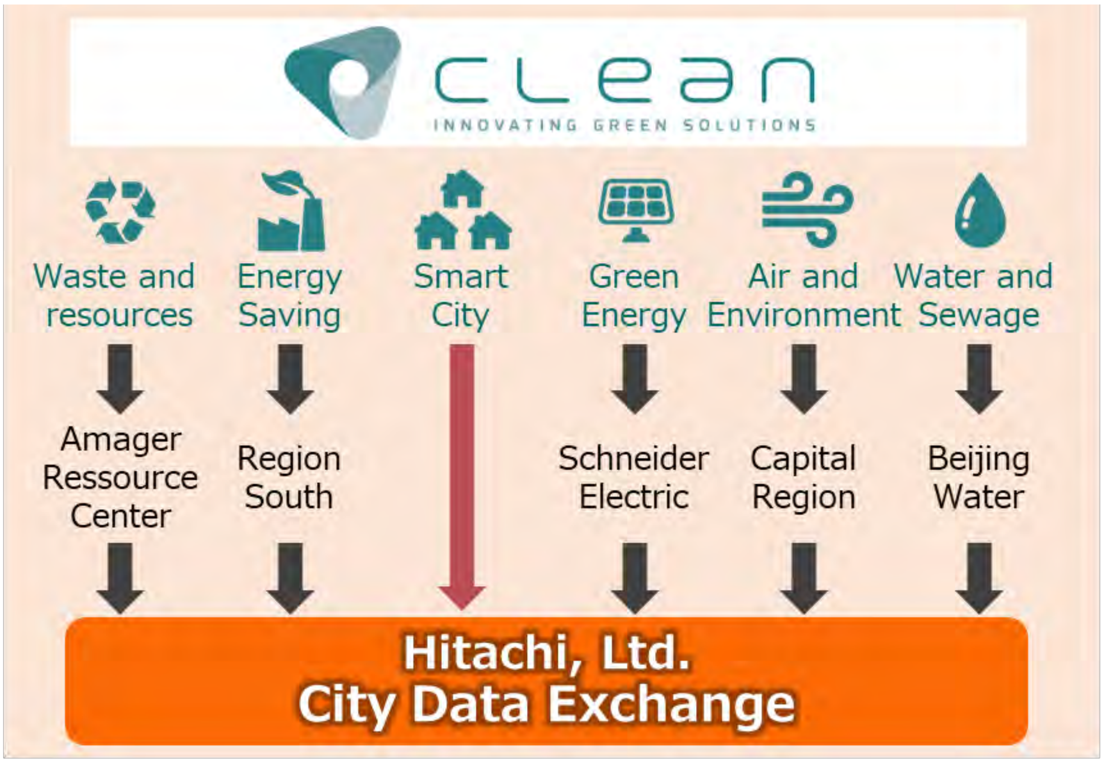


Figure 9: An example of DER utilization from a demonstration in Maui
(NEDO: "The Japan-US Collaborative Smart Grid Demonstration Project in Maui Island of Hawaii State: a case study")

3.3 Data Sharing Among Various Types of Infrastructure

The development of a mechanism to publicly share information among various types of infrastructure (which includes not only electricity, gas, and water but also ICT, automobiles, and logistics) would facilitate the creation of new services. The current mechanism, where different businesses operate and maintain along infrastructural lines, worked during the economic growth period. Moving forward, however, progressing diversification, digitalization, electrification, and motorization will spur infrastructural substitutes and mergers, and will require measures to utilize information technology to streamline and draw value from the conventional, vertical management system. Gathering and utilizing information necessitates not only deregulation around information sharing but also the development of a public information-sharing mechanism driven by the national government. Such mechanism will prevent the excessive monopolization of information and encourage adequate competition in industrial and academic areas, thereby creating innovative industries and employment to contribute to the realization of Society 5.0.

An example of an initiative for data distribution is the City Data Exchange (CDE) project by the City of Copenhagen (Figure 10). The City of Copenhagen aims to be the world's first carbon-neutral city by 2025. The city plans to reduce its CO_2 emission from its current figure of approximately 2 million tons per year to 1.2 million tons by 2025. To achieve this target, the organization CLEAN (formerly Copenhagen Cleantech Cluster), which promotes the deployment of innovative environment- and energy-related technologies in Denmark, collected various data in 2014 pertaining to public and private sectors and used big data analysis to reveal a vision for eco-friendly infrastructure. Since data are valuable assets to their owners, building an open platform is not an easy task. Researchers have pointed out the importance of measures that catalyze a positive spiral, whereby use cases and data can grow hand-in-hand.[18]



CCC: Copenhagen Clean Cluster, BDDI: big data digital infrastructure

Figure 10: City Data Exchange (CDE) Project

[18] LESSONS LEARNED FROM PUBLIC/PRIVATE DATA COLLABORATION https://cphsolutionslab.dk/en/news/city-data-exchange

3.4 Energy and Environmental Performance Evaluation for Cities/City Blocks as a Whole

The redevelopment of a city or a city block should be a strategic redevelopment of infrastructure under an adequate incentive system, based on benchmarked and shared energy/environmental performances of cities and city blocks. The redevelopment should be centered on social values pursued by the local community and conducted with peoples daily lifestyles and industrial structures in mind, rather than individual equipment or buildings. Currently, the available benchmarks for infrastructural redevelopment include those that measure the environmental sustainability of buildings, such as CASBEE (led by Japan)[19], LEED (US)[20], and BREEAM (Europe)[21]. Many of them, however, are certification systems for individual buildings. CASBEE is the only system that aims to provide an environmental benchmark on a regional basis. Yet, on a regional basis, even CASBEEs environmental benchmark is not reflected in the area's property values and does not help enhance the value of the community. Additionally, further enhancement and global roll-out should be pursued since CASBEE use is limited to Japan.

Moreover, sharing data regarding the energy/environmental performance of cities and city blocks would encourage the creation of business opportunities such as energy interchange. Current programs for data management include Building Information Modeling (BIM) and Construction Information Modeling (CIM)[22], whose use has particularly spread across US and Europe. These are used for buildings and local infrastructure from the start of construction until maintenance and management. BIM and CIM prepare 3D CAD data from the construction phase and digitally manage all records of maintenance and repairs; thus, we can expect applications to well-planned urban development policies. On the other hand, BIM and CIM do not readily reflect dynamic changes in the local communities as their main objective is the maintenance of static buildings and infrastructure facilities. The dynamic utilization of information will necessitate an integrated analysis of the private sector's BIM and the public sector's CIM, and therefore the development of a system driven by the national government.

[19] CASBEE (Comprehensive Assessment System for Built Environment Efficiency): an evaluation system for a buildings environmental performance developed by an IBEC (Institute for Building Environment and Energy Conservation) committee.

[20] LEED (Leadership in Energy & Environmental Design): green building certification program developed and operated by the non-profit U.S. Green Building Council (USGBC) for the design, construction, operation, and maintenance of green buildings and properties.

[21] BREEAM (Building Research Establishment Environmental Assessment Method): method of assessing, rating, and certifying the sustainability of buildings developed by Building Research Establishment (UK).

[22] CIM (Construction Information Modeling): a tool allowing real-time collaboration and information sharing using a set of 3D models during each stage of planning, research, design, construction, and maintenance in the civil engineering sector (not to be confused with another similar acronym, Common Information Model).

Periodic disclosures of the energy/environmental performance of cities and city blocks would encourage adequate competition among local communities. As described in Section 3.1, each community can effect changes in its social structure and the lifestyles of individuals by using the aforementioned benchmarks to create, distribute, and trade the communitys unique values.

3.5 Coordination with Bulk Power Systems

The initiatives described above will help develop a society wherein energy values unique to each local community are created, distributed, and traded. They will also lead to the transfer of energy values and supply-demand across multiple local communities. In this scenario, bulk power systems will play the role of linking multiple local communities. We must also anticipate a widening gap in values with heightening local characteristics.

To maintain bulk power systems, local communities will require new values, such as the flexibility to draw from various distributed energy resources (DER) to adjust the energy supply-demand. Conventionally, the electricity transmission and distribution sectors have ensured the reliability and quality of power supply; their roles in doing so had been established. Moving forward, as each local community builds its own unique energy system, they will need to reconsider what values each local community will supply to the bulk power system. Society 5.0 must redesign the division of roles between local communities and the bulk power system, responsible for the 3E+S of society as a whole. Chapter 4 will further detail the link between local communities and the bulk power system.

Chapter 4: Framework to Support Changes in the Bulk Power System

4.1 New Roles for the Bulk Power System

As energy systems change, bulk power systems will assume the important role of improving the 3E+S of society as a whole. In addition, bulk power systems connect multiple local communities as they exchange energy supply, demand, and values. Currently, there is a need to quantify and benchmark the values (other than kWh output) 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. To achieve this, society must reflect in its system the analyses/evaluations of the energy system as a whole, from a technological perspective, and taking into account the systems and policies described in Chapter 6. For example, if the cost of energy supply from renewable energy sources (including subsidies) 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 communities must evaluate the deployed technology and systems/policies pertaining to their energy systems by using multi-dimensional criteria, such as long-term business sustainability, taking into consideration equity and welfare, environmental values, and energy security, instead of merely evaluating the return on investment based on current costs.

Since Japans national territory is made up of large islands lined north to south, the countrys 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 characteristic is one reason why Japan is considered a country/region that may face problems associated with large-scale deployment of renewable energy, such as frequency, voltage, and stability (Figure 11). Japan must promptly solve these domestic issues and globally roll out relevant technologies and know-how to contribute to the international community.

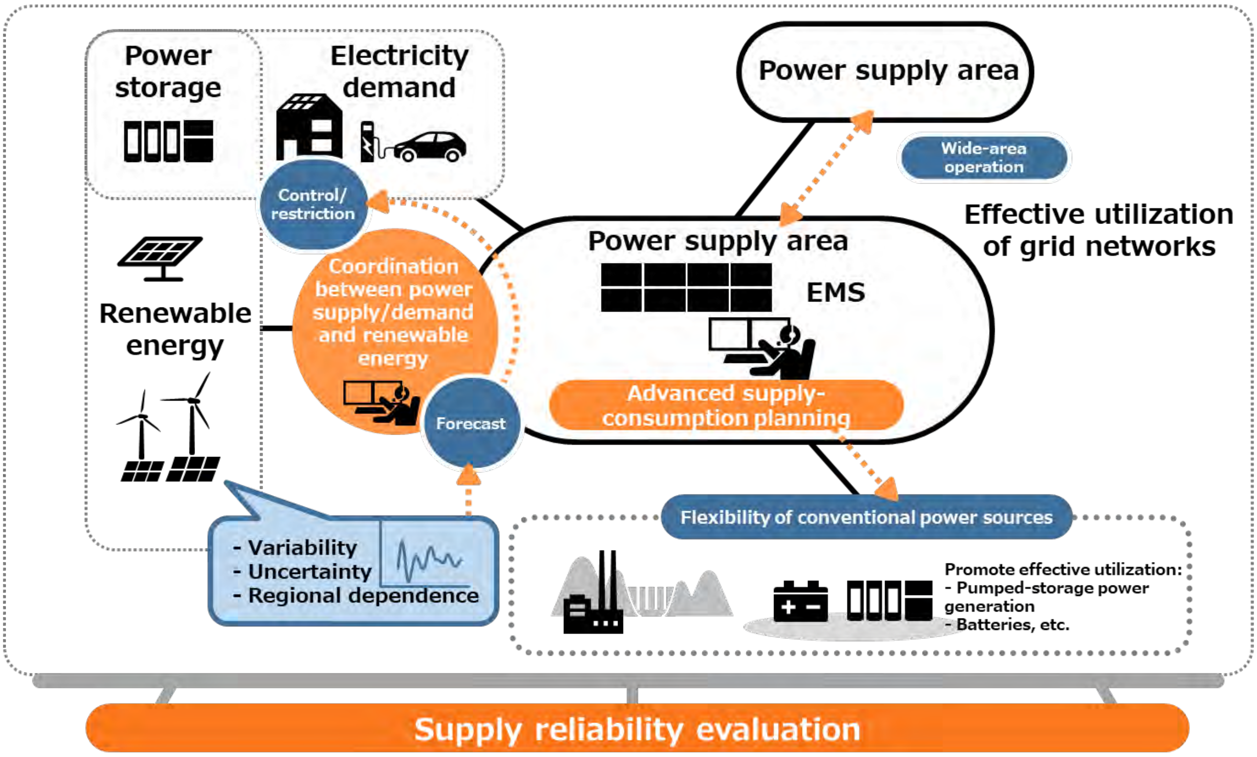


Figure 11: Diagram of electricity supply/demand when renewable energy sources are deployed in large quantities

4.2 Evaluation Environment for Bulk Power Systems

To achieve the expected roles for bulk power systems, We must prepare an environment whereby energy systems (in particular, electricity) 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.

Cooperation among industry, academia, and government is needed to develop a platform to build and share analytical tools and standard data. To achieve government targets such as the 2030 power source configuration indicated in the long-term energy supply-demand outlook and 80% reduction in CO_2 emissions by 2050, we must develop an open environment that enables various parties, such as operators and system designers, to analyze and evaluate a range of future scenarios concerning bulk power systems and local communities, including EV interconnection and hydrogen conversion and storage.

Examples of analytic tools for electricity systems include the electricity supply-demand analytical simulator and the wide-area (grid) stability simulator. The electricity supply-demand analytical simulator was commissioned by NEDO and was researched and developed jointly by the Central Research Institute of Electric Power Industry, TEPCO Power Grid, and the University of Tokyo. It is a tool for evaluating challenges to electric supply and demand in various measures of time, from seconds to years, due to the volatility, uncertainty, and regional dependence of renewable energy. The tool can combine the adjusting capacity of thermal power generation, energy storage functions of pumped-storage hydroelectricity and storage batteries, and cross-regional coordination to study improvements in electricity supply-demand planning and reliability criteria for flexibility (Figure 12). For example, the tool examines the electricity supply-demand and the directionality of technological developments based on the expected large-scale deployment of renewable energy in 2030 to the regional electricity systems in eastern Japan.

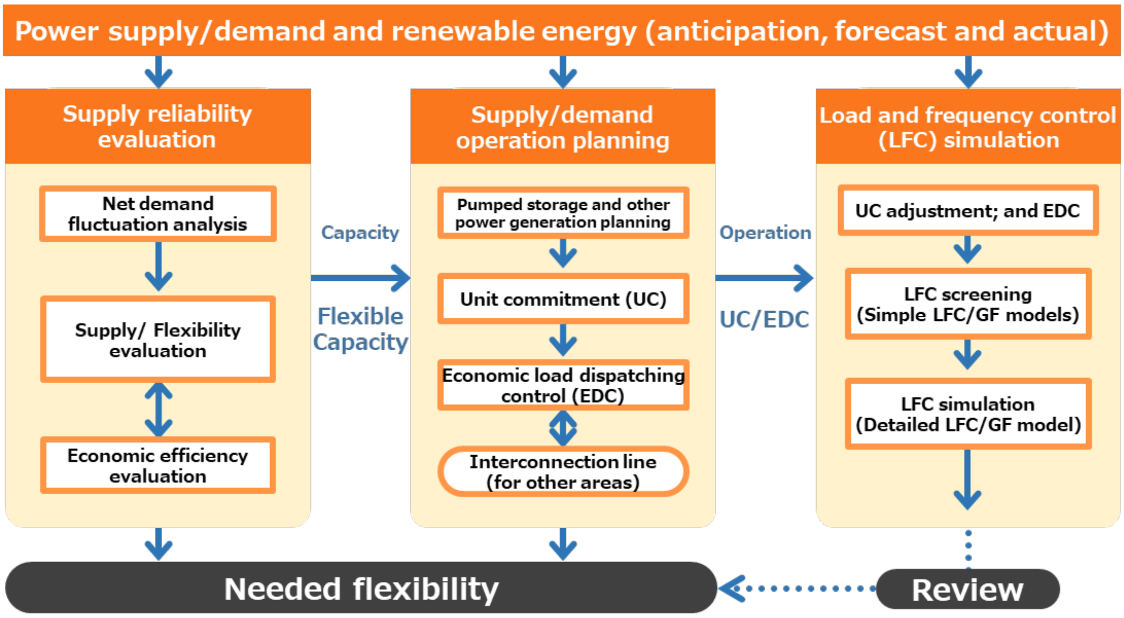


Figure 12: Overview of the electricity supply-demand analytical simulator

On the other hand, Hitachis wide -area stability simulator is an analytical tool to evaluate the various measures for renewable energy deployment from technological and benefit perspectives. The tool makes it possible to consider the deployment limit for renewable energy and the required output suppression amount during the large-scale deployment of renewable energy, while ensuring supply-demand balance and considering transient stability based on anticipated power system failures in various regions. The simulator calculates various evaluative benchmarks, such as changes in annual power generation costs and CO_2 emissions. For example, it has started considerations of the electricity system in east Japan using a stability evaluation model (Figure 13).

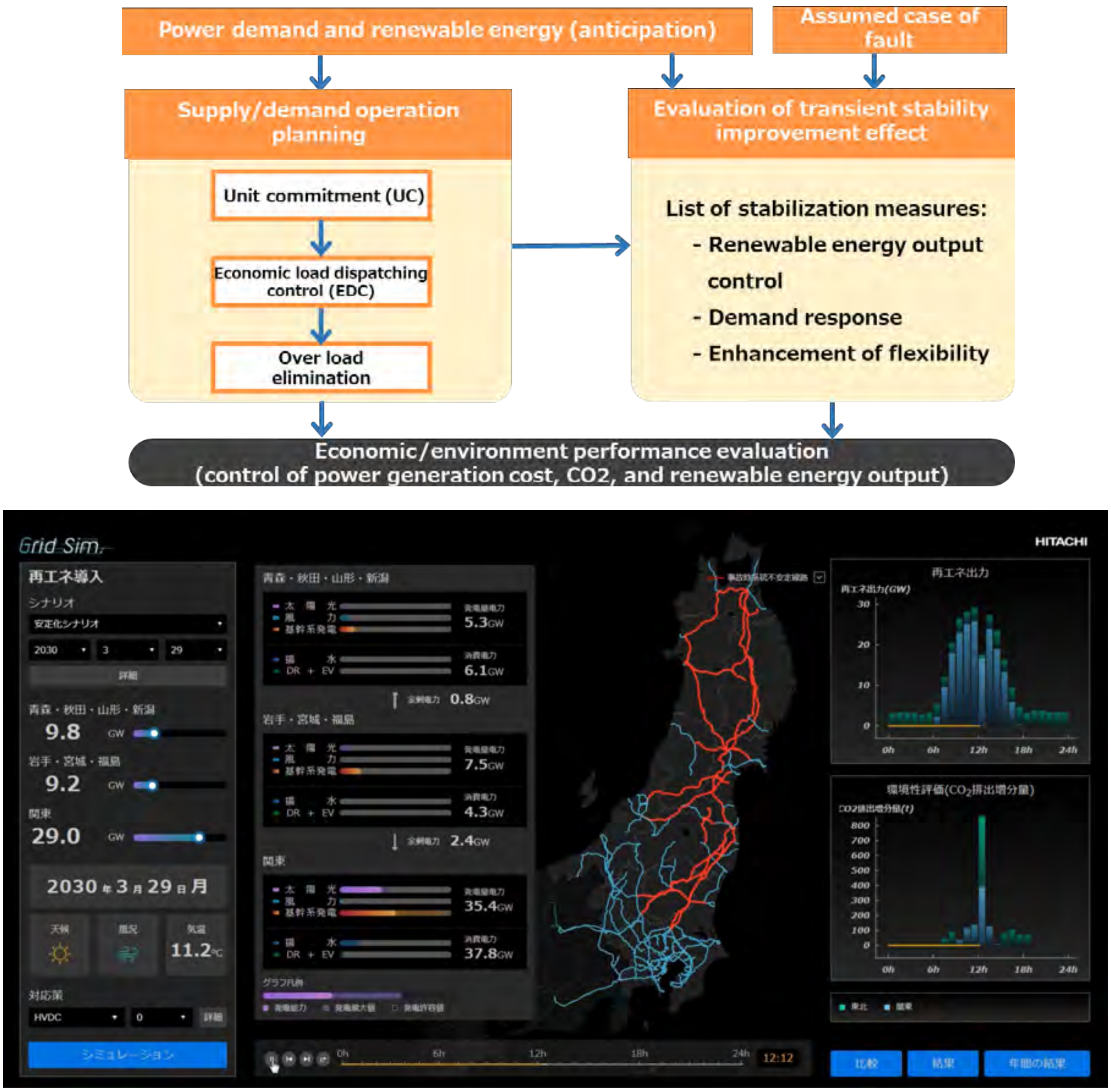


Figure 13: Wide-area stability simulator

Efforts are also underway in overseas countries, such as the initiative at the High-Performance Computing Center[23] of the US National Renewable Energy Laboratory (NREL). The computing center can use data-linking to conduct facility expansion plans, annual supply-demand analysis, including the electrical transmission network, and steady-state/dynamic system analysis. It has completed the Eastern RE Integration Study[24] and is currently working on the Interconnection Seam Study[25] related to the interconnection of the Eastern and Western U.S power grid.

[23] https://www.nrel.gov/news/program/2018/nrel-acquires-powerful-new-high-performance-computing-system.html
[24] https://www.nrel.gov/grid/ergis.html
[25] https://www.nrel.gov/analysis/seams.html

We need to reference these initiatives and collaborate among industry, academia, and government to build an evaluation platform for energy systems that support Society 5.0 from a global perspective, while considering the interchangeability of the data and analysis engines.

4.3 Coordination with Local Communities

As the entire energy system will utilize the values possessed by demand-side resources, future energy systems will need to incorporate and implement new control technologies to digitally connect bulk power systems with local communities, and, concurrently develop market trading systems and systemic designs. For example, we must develop new control technologies such as virtual power plants (VPPs), demand responses, and smart inverters for renewable energy. We must effectively utilize the potential of existing equipment and maximize the cost-effectiveness of the social system by assigning part of the supply-demand adjustment function (presently performed by thermal power and pumped-storage hydropower generation facilities) to the energy control processes of local communities. To this end, it will be important to develop IT infrastructure to link the enormous facilities of local communities, and create control schemes to maximize effects, incentives, or other rule schemes. As described in Chapter 3, we consider an effective approach to be mutual cooperation by requiring local communities to uphold kW, ΔkW, and other "quality"-related values across the entire power system either directly (control commands) or indirectly (incentives), and utilizing the adjusting capacity of local communities. 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 based on the output forecast and output control for renewable energy, as well as the cooperative operation and control of existing power sources and storage batteries. The project optimally combines measures for excess electricity, fluctuation mitigation, and planned power generation for the operation of the power system. The project also tests the coordinated operations of multiple dispersion-type control systems, assuming resource aggregation and balancing groups that may accompany future reforms of electricity systems (Figure 14).

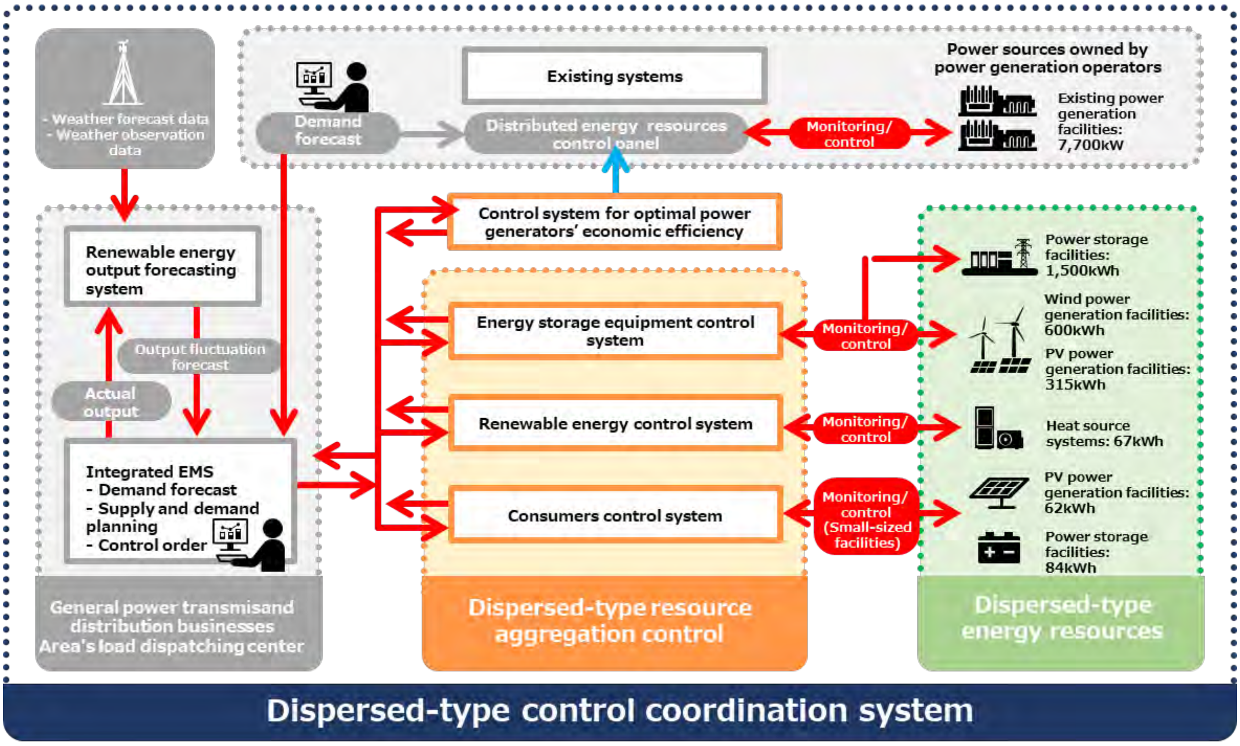


Figure 14: Demonstration of a model electricity system based on the anticipated energy mix for 2030

(Prepared on the basis of data from the TEPCO website[26] (April 13, 2017))

4.4 Evolution into a Cyber-Physical Evaluation Platform

Moving forward, we will further need to evolve the platform used to evaluate the bulk power systems described in Sections 4.2 and 4.3. In the past, bulk power systems had increased their contributions to society through total optimization achieved through coordination with neighboring bulk power systems in wide-area operations. In the future, bulk power systems will increase their coordination with power distribution grids and consumers in local communities, and will evolve to coexist with other non-energy industries (cross-industry), such as mobility systems (Figure 15). Evaluation platforms will develop into a cyber-physical system (CPS) which links individual analytical tools, incorporates real-world data, and enables operations in the cyber space.

[26] http://www.tepco.co.jp/pg/company/press-information/press/2017/1406851_8686.html

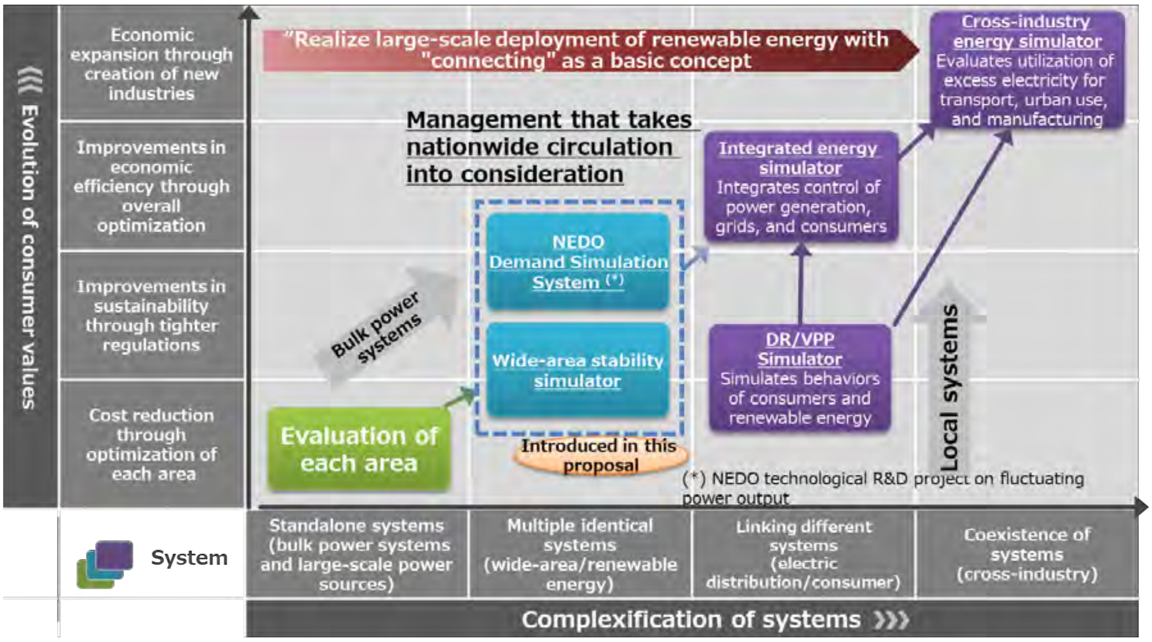


Figure 15: Evolution of evaluation platforms for energy systems

Chapter 5: Conceptual Design of the Evaluation Platform and Data Sharing

5.1 Evaluation Platform

To gain a social consensus on the future visions of bulk power systems and local communities, we must establish an environment that can objectively analyze and evaluate the energy systems of society as a whole. The platform should evaluate the cost-effectiveness (potential returns on investment) of solving the issues selected through discussions with stakeholders, and should be developed as a shared technology and shared asset with collaboration among industry, academia, and government. We believe that this platform will be useful for the revitalization of the energy market if it is used not only in a public capacity (institutional and policy planning) but also by renewable energy plants, aggregators like VPP, EV storage batteries, and by operators of new businesses such as the utilization and conversion of hydrogen.

The following three items should be considered in designing the aforementioned evaluation platform:

(1) Define users who will use the evaluation platform and identify their required specifications and functions.

(2) The evaluation platform assumes the information and data sharing of the power system, power generation, and demand, but each possesses 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 to disclose and publicize the scope of disclosure. Public release should be determined on the basis of the required specifications and functions described in item 1.

(3) Specify an appropriate operator to provide continuous improvements and updates to the evaluation platform.

Table 1 shows the proposed use cases that utilize the evaluation platform. Table 2 summarizes the functions (= analytical tools) and information/data required for Use Cases 1, 4, 7, and 8 (see Appendix 2 for details). We can readily anticipate multiple utilization proposals—from vision and policy proposal to business feasibility evaluation, including future outlook; these can be converted into the creation of new businesses and regional revival/revitalization by urging the entry of new market players. In addition, Table 2 shows a system configuration “greater than 154kV” in the field “required information and data”; however, the level of detail required depends on the use case. Thus, it is necessary to distinguish between “public release” to the general population and “disclosure,” whereby the owner of the information/data reveals the information to a limited number of appropriate parties.

Below, we will discuss the ideal evaluation platform for bulk power systems and local communities. Stakeholders vary when discussing the overall optimization of 3E+S through bulk power systems and when discussing the energy systems of local communities. It is necessary to prepare analytical tools and information/data suitable for each. As described in Section 1.1, next-generation energy systems will be rebuilt assuming a symbiotic relationship between bulk power systems and local communities. Thus, a coordination mechanism will be needed to integrate the rapidly increasing distributed energy resources (DER). The mass deployment of VRE will necessitate adjusting capacity between bulk power systems and local communities. Beyond this, there will also be established a relationship whereby new values such as electricity storage, energy reserves, and CO_2 emissions will be traded. Functionality to evaluate such transactions will likewise be required (Figure 16).

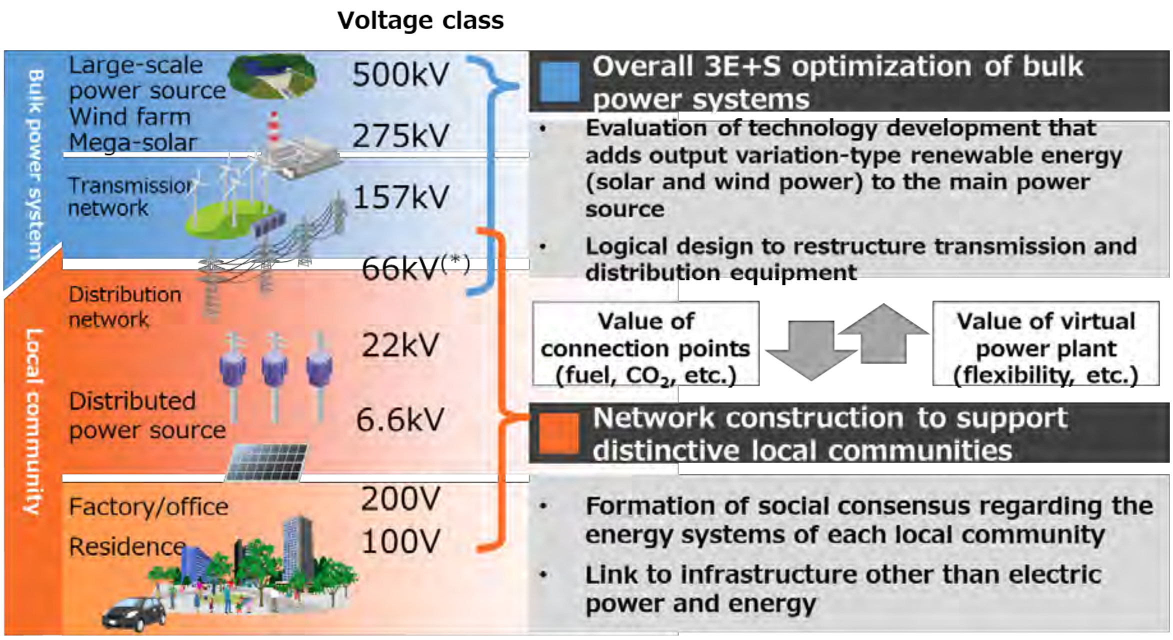
Table 1: Simulator use case diagram

#	Content	Stakeholder	Use case
1	Vision / policy proposals	Citizens/universities/think tanks/media/legislature /regulatory agencies	• Examine and propose future strategies for environment and energy • Examine renewable energy deployment and incentive systems
2	Proposal of control, operation, and rules of power systems	Universities/research institutes/regulatory agencies	• Propose new management methods for power systems (voltage, frequency, maintenance of stability, etc.) • Propose operational standards/rules
3	Evaluation of electricity consignment	Universities/regulatory agencies/power transmission & distribution co	• Examine consignment fees for future power systems • Estimate congestion of power transmission/ distribution lines caused by consignment • Plan transmission line facilities
4	Feasibility evaluation of renewable energy generation	Wind energy co /photovoltaics co/power transmission & distribution co	• Estimate annual power generation and output control amounts • Calculate interconnection costs
5	Impact evaluation of the interconnection of distributed power supply	Universities/power transmission & distribution co	• Evaluate stability and reliability during system interconnection
6	Feasibility evaluation of adjusting capacity and ancillary business	Local energy co/power plant /power transmission & distribution co	• Forecast hourly adjusting capacity (kW, △kW) • Quantitatively evaluate the stability and reliability contributed by provision of adjusting capacity
7	Feasibility evaluation of P2P energy trading	General consumers/aggregators/ power transmission & distribution co	• Analyze future business scenarios • Test suitability of transmission and distribution network usage costs through P2P trading
8	Assessment of EV charging infrastructure	EV companies/city & city blocks/power distribution companies/local government	• Make assessments (energy quality, economic effects) for application of charging infrastructure development • Estimate overload and voltage fluctuation at interconnection points • Calculate effects of charge/discharge shifts and reactive power control

Table 2: Analytical tools and information/data required by each use case (See details in Appendix 2)

Use case # (refer to prev page)			1	4	7	8
Content			**Vision/policy proposals** Prepare future strategies for environment and energy	**Feasibility evaluation of renewable energy generation** Estimate annual power generation and output control amounts	**Feasibility evaluation of P2P energy trading** Analyze future business scenarios	**Assessment of EV charging infrastructure** Make assessments (energy quality, economic effects) to apply for development
Stakeholder			Citizens/universities/ think tanks media/ legislature/ regulatory agencies	Wind energy co/ photovoltaic co/ power transmission & distribution co	General consumer/ aggregators/ power transmission & distribution co	EV companies/city & city blocks/power distribution co/local government
Analytical tool (*)			A·B·C	A·C	A	A
Required data (extract)	System configuration	≧ 154kV	○	○	-	-
		66kV	-	○	-	-
		≦ 22kV	-	-	-	○
	Power source	Actual output/ characteristics of large-scale power plants	○	○	-	-
		Actual output/ characteristics of renewable energy	○	○	○	-
	Actual demand	≧ 154kV	○	○	-	-
		66kV	-	○	-	-
		≦ 22kV	-	-	○	○
		Smart meter data	○	-	○	-
	Future outlook	System configuration	○	○	-	-
		Power supply configuration/ arrangement	○	○	-	-
		Demand forecast	○	○	○	○
		Weather conditions	○	○	○	-

○: required; -: not required; (*) A: Evaluation of supply reliability, B: Plan for supply-demand management, C: Evaluation of system stability



(*) 66kV-class equipment data and measurements are contracted accordingly and cross-referenced in the evaluations of the bulk power system and local community.

Figure 16: New values traded between bulk power systems and local communities

(1) Evaluation platform required to change the bulk power system

As VRE becomes the main source of energy, it must be accompanied by the logical restructuring of power transmission and distribution facilities. Achieving this with minimal social cost will require the preparation of information and data to serve as assumptions to the analytical tools that evaluate bulk power systems. The analytical tools include the electricity supply-demand analytical simulator and the wide-area stability simulator described in Chapter 4. Information and data will ideally include the disclosure of power generation amounts, as well as system information (equipment configuration and status) at voltage class 275kV or greater (partly includes 157kV / 66kV). As mentioned above, main issues pertain to those concerning information security for key infrastructure and the protection of information related to the competitiveness of power plants. One way to realize an open environment would be, for example, to establish a neutral organization operating an evaluation platform and to build a framework in which information and data can be disclosed to legal entities pre-approved by the neutral organization. Furthermore, a data encryption mechanism will be needed so as to not impede the competitiveness of corporations, along with a verification system by a third party. In the bulk power system, the operating costs for power transmission and distribution companies may significantly change depending on the mass deployment and population dynamics of localized VRE; we must aim for overall optimization, taking into account energy supply costs by site, such as nodal price (energy supply cost by site) and LMP (Local Marginal Price: marginal price by site). The evaluation platform also helps evaluate the effectiveness of such policies and systems and gain social acceptance.

(2) Evaluation platform required for new endeavors by the local community

In Society 5.0, individual lifestyles will take center stage, creating a distinctive energy system for each local community. Various types of infrastructure, such as electric power, gas, water supply, ICT, transportation, and distribution, will cooperate to form new values. The energy system will require new measures, such as ways to handle sharp spikes in energy demand accompanying the rapid charging needs of EV, as well as changes in power flow. The energy systems will need to advance overall optimization in the local communities, including heat and energy reserves, and will also play a role in contributing to the stable operation of the bulk power system through the provision of adjusting capacity such as VPP and DR. The development of an evaluation platform is necessary to advance these measures and initiatives; in this instance, the information and data of power distribution systems will be required.

5.2 Framework for the Disclosure/Release of Information and Data

Although the evaluation platform assumes the sharing of information and data about the power system, power generation, and demand, there are many limitations, such as security issues like important infrastructure, protection of information related to the competitiveness of power producers, protection of personal privacy, etc., that need to be disclosed and publicly released to an appropriate extent. Table 3 summarizes the measures and issues of the disclosure and public release of the information and data.

To expand data use, the importance of data sharing must be agreed upon by stakeholders in industry, academia, and government. They must also quickly make rules pertaining to the disclosure, release, and sharing of information. It is desirable to share not only the present state but also data pertaining to power systems, generation, and demand that reflect plans and future scenarios with details as close to reality as possible. In addition, for intellectual property that may be difficult to disclose (such as generator-specific control parameters), measures should be available to conceal sensitive data through encapsulation. For example, the Institute of Electrical Engineers of Japan (IEEJ) has released standard power system models (i.e., EAST30, WEST30[27], etc.) to use in system stability analysis, but more detailed data are needed if we are to assume the future mass deployment of VREs (which are currently localized) and accelerated EV deployment on the demand side. Overseas, the National Grid (UK) and ENTSO-E (Europe) have published their system configuration and power flow status; these can be referenced as a form of data sharing. It will be necessary to also reference these overseas cases and build out a management framework, such as operation by a neutral organization and preparation of a third-party monitoring mechanism.

[27] EAST30, WEST30: Names of the standard model grids developed by the IEEE. The numbers reflect the number of generators.

Table 3: Issues and measures for the disclosure and public release of information/data

#	Category	Issue	Proposed Measures
1	Ideal form of data	Energy system security (ex. cyber terrorism)	• Limiting stakeholders with access to information • Disclosure of abstracted data
2		Protection of proprietary information amid corporate competition (ex. leaked trade secrets)	• Black box processing • Statistical information
3		Protection of consumer privacy (ex. misuse of private information)	• Data anonymization • Statistical information
4		Assumption of future uncertainty (ex. expected number of EVs)	• Creation and publication of multiple scenarios among stakeholders in consideration of uncertainty
5		Promoting information disclosure among other operators/ infrastructure	• Accumulation and scaling of business models (use cases) via information use
6	Management system	Development/ maintenance of an open analytical engine Database operation	• Launch of new organizations or identification of the responsible organizations • Platformization of system and operational aspects

5.3 Evaluation of Measures for Power Systems with the Increased Deployment of Renewable Energy

Measures will be needed for bulk power systems and local communities with the large-scale deployment of localized VREs. In Japan, a variety of software measures, such as advanced plans for supply-demand management, have been applied, demonstrated, and proposed. Similarly, hardware measures such as new technologies for protection and control using synchronous phase measuring instruments (PMU) or smart inverters to eliminate the lack of synchronization ability (Figure 17) have been devised. It will be ideal to begin with software measures achievable with minimal investment, and subsequently introduce non-firm connection or N-1 Restriction proposed by the Organization for Cross-Regional Coordination of Transmission Operators, Japan (OCCTO) while making maximum effective use of VRE power generation, that is, avoiding output control, taking into account advanced protection and control technologies such as the online stability control system. In addition, we predict that emergency response will become more difficult with the large-volume deployment of distributed energy resources (DER) and VRE; one challenge will be to develop protection and control technologies that can even anticipate cascading events (Figure 18).

Deployed renewable energy: Less → More; Soft → Hard

	Challenges / Measures	Supply/demand adjustment		Power system stability				Power supply quality		Case
		Long period	Short period	Step-out phenomenon	Frequency phenomenon	Voltage phenomenon	Equipment overload	Voltage level	Higher harmonics	
Basic measures	Wide-area supply-demand adjustment	○	○							OCCTO functions
Basic measures	Suppression of voltage spikes						○	○		JIS standardization of PCS
Basic measures	Output control (VRE)	○					○			Supply priority rules for VRE interconnections
In consideration	Non-Firm connection	○					○			Proposed OCCTO functions
In consideration	N-1 Restriction	○					○			〃
In consideration	DR/VPP	○	○							NEDO Smart Grid demonstration in Maui
Further measures	Grid stabilization system			●	●	●	○			Online pre-computation system
Further measures	Dynamic optimization of power flow	○	○			●	○			Online optimal power flow (OPF) calculations
Further measures	Wide-area system protection & control			○	○	○				PMU use
Further measures	Smart inverter	○	○	○	○	○	○	○	○	Simulated governance and synchronization capacity
Further measures	Upgrade of system equipment	○	○	○	○	○	○	○	○	HVDC etc.

PCS: Power Conditioning System; VRE: Variable Renewable Energy; HVDC: High Voltage Direct Current; OPT: Optimal Power Flow Calculation; PMU: Phasor Measurement Unit; FC: Frequency Converter; DR: Demand Response; VPP: Virtual Power Plant

Figure 17: Various measures for power systems with enhanced deployment of renewable energy[28]

[28] N-1 Restriction: a measure to increase transmission capacity by suspending power supply in the event of component failure (Source: "Study of the Japanese version of Connect & Manage," Organization for Cross - Regional Coordination of Transmission Operators, Japan (OCCTO), January 24, 2018)
Online power system stability control: Measure that avoids wide-area blackouts by using pre-computation to counter assumed power system faults and enhance the normal power transmission limit（Source: "Development of a stability control system for bulk power system-integrated power grids using cutting-edge technology," Chubu Electric Power New Technology/R&D news, No.158, 2018-2）

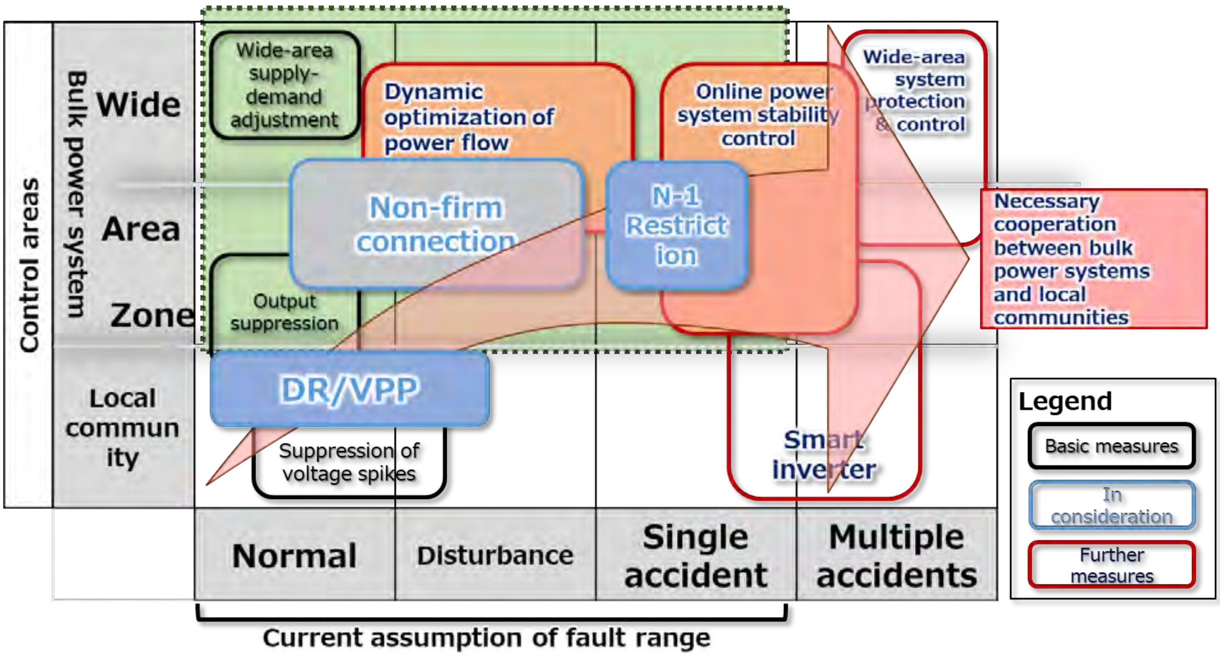


Figure 18: Advancements in grid system technology for next-generation energy systems

5.4 Sample Quantitative Evaluation Using a Simulator (Trial Introduction)

As an example of evaluation platform use, we use a wide-area stability simulator to quantitatively evaluate the state of output control in eastern Japan when a large amount of renewable energy is deployed in the Tohoku region. The focal point of this trial is how effectively the renewable energy is transmitted from the Tohoku region to the Kanto region, considering the various types of power systems shown in Figure 17 and Figure 18.

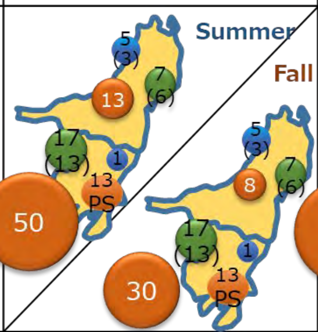
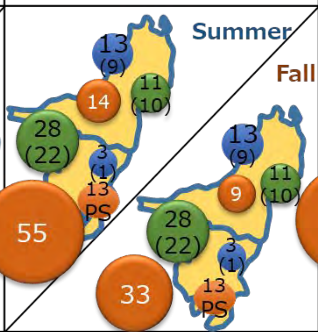
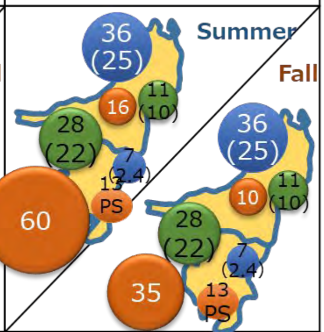
(1) VRE deployment in 2030/2040/2050 (assumed)

We set the renewable energy ratio to total generated power as 22-24% in 2030 (VRE 14%), 40% in 2040 (VRE 25%), and 60% in 2050 (VRE 40%) (Table 4). We referenced the Basic Energy Plan for the 2030 figure, while the 2050 figure is based on the CO_2 reduction targets in the Paris Agreement and corresponds to the centralized decarbonization scenario in Chapter 2. In addition, the VRE capacity in Table 4 refers to Japan's total capacity based on a study by the Japan Photovoltaic Energy Association (JPEA), and was distributed to each area proportionate to the deployed amount in 2016. In addition, we fluctuated energy demand between 0.8 and 1.2 times 2016 figures because of a high level of uncertainty from economic development and electrification.

(2) Power system measures

The output control amount of VRE (= VRE suppression amount) was used as the benchmark for evaluation. We considered the four measures shown in Table 5 to escape output control. We set the starting point as the fortification plan for the Tohoku-Tokyo transmission line proposed by OCCTO and assumed N-1 Restriction, DR/EV utilization, and online power system stability control. In addition, we assumed that we can obtain cooperation from the Tohoku area for 5% of demand when using DR and 20% of batteries when using EV.

Table 4: VRE deployment in 2030, 2040, and 2050 (assumed)

Time period		2030	2040	2050
VRE ratio(%)		14 (RE 22-24)	25 (RE 40)	40 (RE 60)
VRE capacity (GW) All Japan	PV	64	104*1)	104*1)
	Wind power	10	16	86*2)
Assumed VRE and demand in Tokyo and Tohoku areas	VRE/demand distribution ※Demand in Tokyo/Tohoku Summer: heavy 63 GW Winter 50 GW Spring 45 GW Fall 38 GW GW 33 GW PV / Wind / Demand Capacity GW ():normalized power generation of region			
	VRE output (GW)	18.5 (12pm)	38.4 (12pm)	53.7 (12pm)
	Demand (GW)	Same as 2016	Assume 0.8-1.2x of 2016 values (Above values reflect 1.1x (2040) and 1.2x (2050))	
	EV capacity (GW)	1.6 (1.3 mil units)	5.1 (4.1 mil units)	10.2 (8.25 mil units)

Assumptions: *1) Calculated by JPEA (Japan Photovoltaic Energy Association); *2) separately calculated by Hitachi based on *1); used 13.2 GW pumped-storage hydropower for renewable energy.
EV: Electric Vehicle, VRE: Variable Renewable Energy, RE: Renewable Energy; PS: Pumped-storage hydropower

Table 5: Measures for the power system considered in the current evaluation

Measure	Explanation	Application period	
		2030	2050
(1) No measures	• Enhancement of power system based on OCCTO plan	○	○
(2) N-1 Restriction	• Increase transmission capacity by suppressing power supply during failures • Assume 100% transmission is possible for transmission lines with two or more circuits	○	○
(3) Addition of DR	• Reduce suppression amount by requesting consumers to increase demand during suppression of renewable energy generation • Assume cooperation from 5% of consumers	○ Tohoku 0.5 GW	○ Tohoku 0.6 GW
(4) Addition of EV	• Reduce suppression amount by requesting EV charging during suppression of renewable energy generation • Assume cooperation from 20% of EVs	○ Tohoku 0.4 GW	○ Tohoku 2.3 GW
(5) RAS (online power system stabilization)	• Online stability control system to restrict unstable generator post-accident	○	○

DR: Demand Response; EV: Electric Vehicle; RAS: Remedial Action Scheme (online power system stability control)

(3) Sample analysis results (See Appendix 3 for details on the analysis method/model)

Figure 19 shows the evaluations during the fall cross-section in 2050, when there is low demand. Here, we suppressed the output of PV, except for the rooftop-type, then controlled wind power output. In the initial condition (1), the power transfer capacity from the Tohoku region to the Kanto region is set to 10 GW because of limitations in heat capacity. This shows that only 5 GW can be generated in this cross-section versus the 21 GW normalized capacity (averaged over the whole region) of the Tohoku region, which has a wind power-generating capacity of 30 GW. N-1 Restriction will expand the power transmission capacity between Tohoku and Tokyo to 16 GW, and shall improve the amount of generated wind power to 11 GW (Figure 19 (2)). Although N-1 Restriction will ideally double the power transmission capacity, in this case, the power system stability becomes a constraint and caps the capacity at 1.6 times. DR and EV utilization (Figure 19 (3)) and online power system stability control (Figure 19 (4)) have gradually evaded output control; in this example, it is possible to generate up to 15 GW versus the normalized regional capacity of 21 GW.

Figure 20 shows the results of sensitivity analysis with respect to energy demand. The demand is varied by 0.8, 1.0, and 1.2 times the 2016 figure. The ratio of renewable energy will be the value shown in Table 4 regardless of demand: that is, the VRE deployment amount will be increased in proportion to the demand. Energy output control is unnecessary (even for 2050) in cases where demand falls by 20%, but the status quo projection scenario incurs an annual loss of 100 billion yen or more. The power transmission capacity between Tohoku and Tokyo becomes critical in limiting the amount of generated VRE. The anticipation of demand is important to plan future power systems. It is desirable to use this data not just to determine the capacity of interconnections but also to study the geographical design for VRE installation.

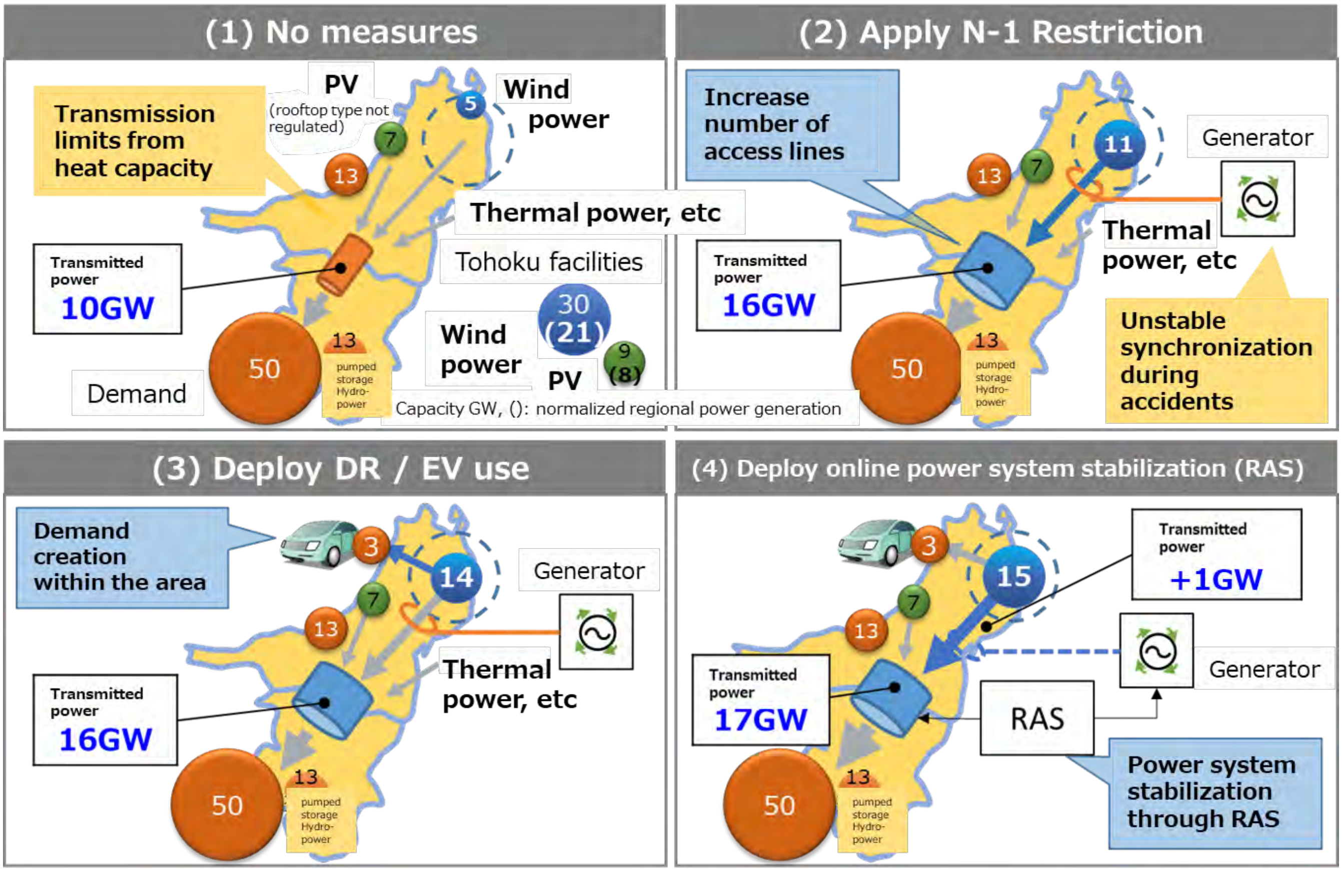
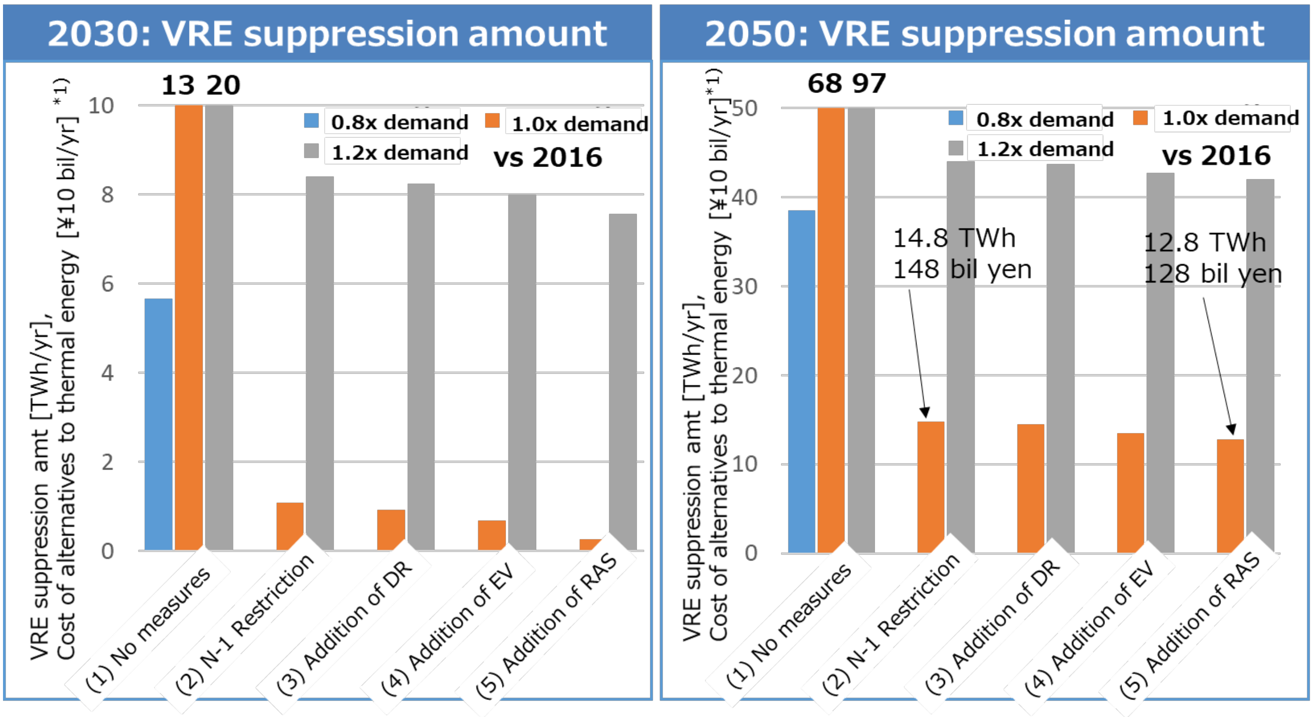


Figure 19: Sample analysis results (August 9, 2050, 12:00; demand equivalent to 2016)



* 1) Assumes the replacement of VRE with LNG power: converted as 1kWh = ¥10; (1) desktop analysis, (2)-(5) simulation analysis

Figure 20: Relationship between various measures and deployable amount of renewable energy

Chapter 6: Systems and Policies to Address New Challenges and Reforms

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 to implement them as long-term plans (Section 6.1). Section 6.2 reviews systems and policies to promote the restructuring of bulk power systems and local communities. For the former, we propose simultaneously accelerating investment and efficiency through performance-driven policies. For the latter, we seek to build a system 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 should be built to circulate funds and promote innovation to facilitate the conversion of the energy system (Section 6.3). Using the various evaluation platforms described in Chapter 5, we develop a long-term energy strategy based on scientific evidence, and create a positive cycle of investment and revitalization of regional economies.

6.1 Fleshing Out the Future Vision of Energy Systems

In Chapter 2, we quantitatively evaluated the energy system of the future using the technology selection model. However, a more detailed examination will require price models based on supply cost, technological evaluation through a power system simulator, and an economic model[29] that assesses the impact of the emergence of energy systems on macroeconomics. In addition, we implement a scientific review mechanism and incorporate the findings from multiple stakeholders to enhance the relevance and objectivity of the scenarios, and utilize them as a part of an open decision-making process (Figure 21). In addition, we will flesh out the future vision of the energy system and identify what technological developments and investment areas are needed to convert these into long-term investments.

[29] In cooperation with the National Institute for Environmental Studies (NIES), H-UTokyo Laboratory uses the applied general equilibrium model (AIM/CGE) to evaluate the impact of an energy system reform on macroeconomics. The calculations will be published separately. Reference material for AIM/CGE: https://www.kantei.go.jp/jp/singi/tikyuu/kaisai/dai06tyuuki/siryou2/5_2.pdf

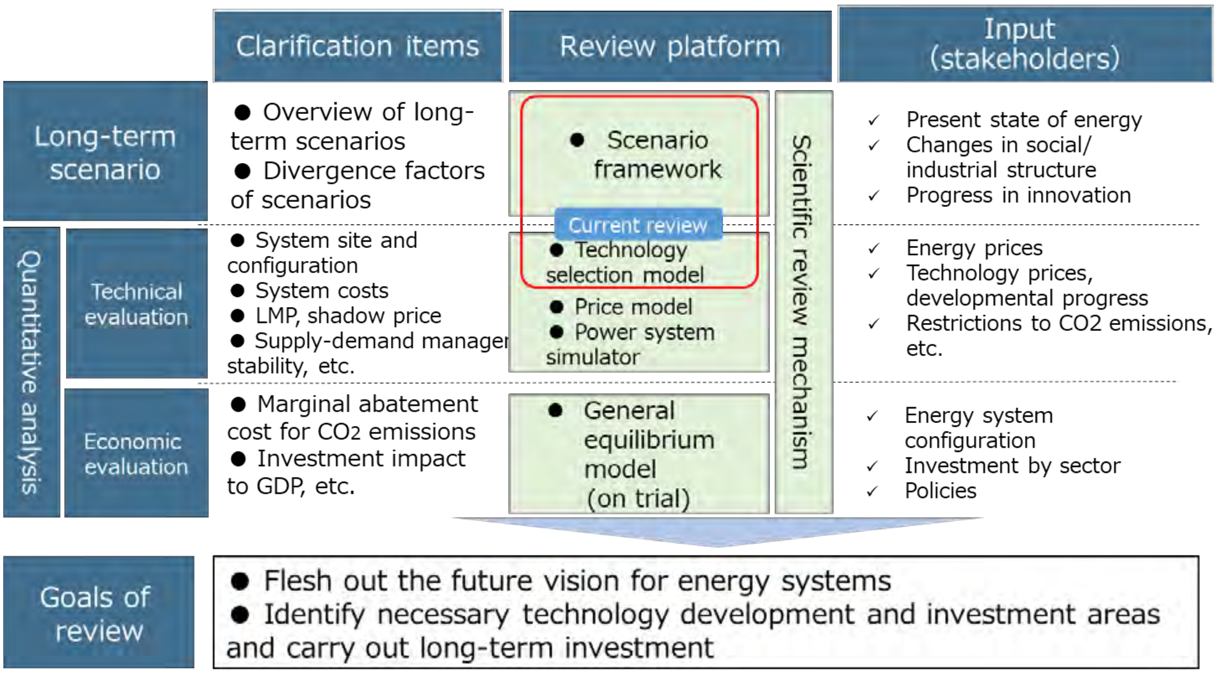


Figure 21: Framework to consider long-term energy scenarios (future)

In addition, to realize the future energy system, it is necessary to carry out the following items while incorporating knowledge from stakeholders:

- Clarify the vision for future energy systems in each scenario based on objective grounds and within the aforementioned framework examining long-term energy scenarios (Figure 21)
- Quantify the KPI that energy systems should achieve, such as power source configuration, equipment configuration of consumers, and the reduction and efficiency of CO_2 emissions
- Build a mechanism to coordinate the energy system with mid-to-long-term national land plans
- To realize the above three items, create an open framework that transcends the bounds of the energy system and allows for cross-sector discussion among industry, academia, and government, and implement EBPM[30]

6.2 Measures to Promote the Reconstruction of Bulk Power Systems and Local Communities

(1) Performance-driven policies that support the transformation of bulk power systems

[30] Evidence Based Policy Making: In this context, hypothesizing and examining policy options based on objective data (evidence) such as statistics or simulations, and hosting open discussion among stakeholders to formulate policies.

As mentioned in Chapter 4, the bulk power system plays a role in the total optimization of 3E+S for society as a whole. Investments in the bulk power system should be evaluated not only in terms of the economic benefits of the created innovation but also in terms of its outcomes rooted in various values, such as energy security and sustainable development goals (SDGs[31]). When setting investment targets, it is desirable for multiple stakeholders to openly discuss and decide the values that the energy industry should realize from the perspective of 3E+S. In addition, the measure of target achievement is quantitatively evaluated using a simulator and standard benchmarks; communities should aim for continuous improvement by carrying out PDCA with stakeholder involvement. Such policies that realize values centered on outcome-based evaluations are called "performance-driven policy." Specifically, the following items need to be implemented when introducing performance-driven policies:

- Incorporating the necessary costs into the power transmission and distribution sectors fee revenue in order to realize the investments in next-generation systems, measures to prevent deterioration, cost reduction, and measures against uncertainty and large-scale disasters
- Analyzing the costs and benefits of the investment, taking into consideration reductions in CO_2 emissions and supply stability, and establishing cost-sharing rules[32]
- Business operators can intelligibly present added-value as an outcome in order to gain the understanding of consumers and ensure accountability
- Plan the infrastructural system by back-casting from scenario analysis and future vision, and reflect the cost of realization into business revenues
- Flesh out the future vision of the energy system with collaboration from industry, academia, and government (Chapter 2), and discuss about the evaluation platform (Chapter 5)

An example of an overseas preceding initiative would be UK' network price control policy, RIIO.[33]As Figure 22 shows, the revenue from power transmission and distribution businesses includes the base revenue based on total cost and compensations according to the degree of achievement of environment and energy security targets. It also reflects investment for technological development, thus encouraging innovations. It also reflects uncertainties arising from inflation and other economic fluctuations, ensuring medium- to long-term predictability for operators.

[31] SDGs: Sustainable Development Goals

[32] Fair and transparent cost-sharing rules must be established regarding fortifications to the grid to deploy the unevenly distributed (localized) renewable energy.

[33] Revenue=Incentive＋Innovation＋Output: U.K.’s performance-driven policy concerning power transmission and distribution businesses

Furthermore, RIIO provides incentives[34] for cost reduction to curb price increases. Target setting for and review of RIIO involve a range of stakeholders. RIIO thereby concurrently functions as a communication platform. Thus, RIIO encourages investments and innovations and helps reform the energy systems under social consensus while curbing price increases. Germany and the United States have each utilized their own schemes to create investment incentives.[35]

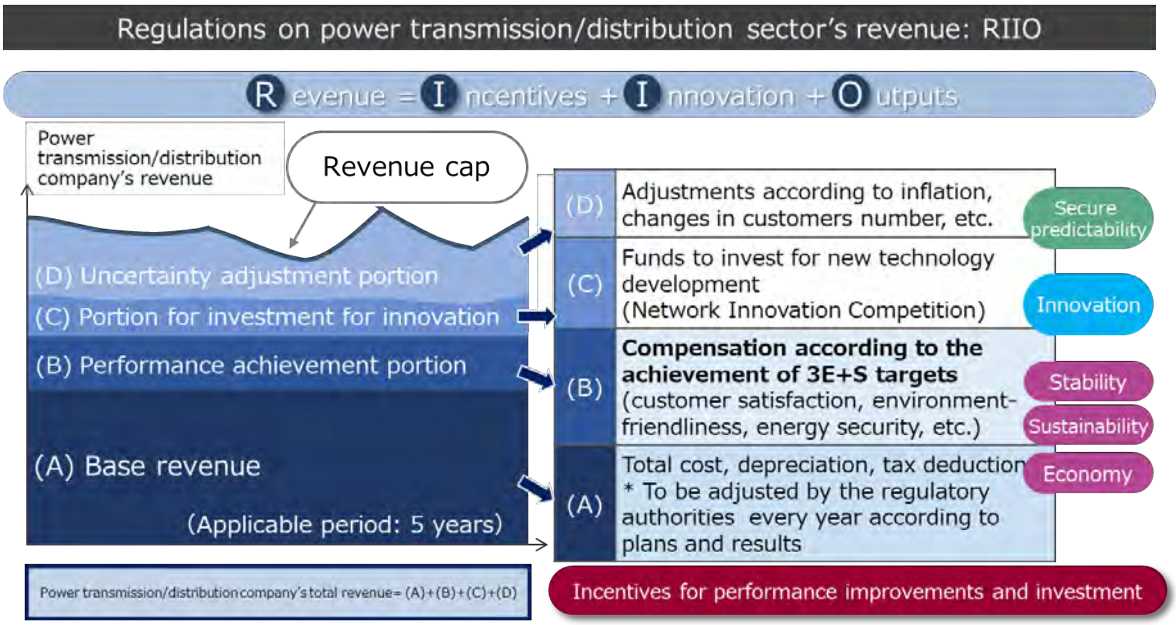


Figure 22: UK' RIIO

In addition, the UK has established a process to integrally examine the future supply-demand scenario and countermeasure options, as well as the revenues of the power transmission and distribution sector, which serve as the foundation to achieve these measures (Figure 23). By back-casting from multiple scenarios, the process formulates an investment plan by evaluating the networks issues in each scenario over the immediately preceding 10 years. The process uses the Least Worst Regret method[36] to select the measure out of the group of options to incorporate in the investment plan. This method makes it possible to consider measures that are flexible with respect to future uncertainty and ensure investment predictability while maintaining accountability to consumers.

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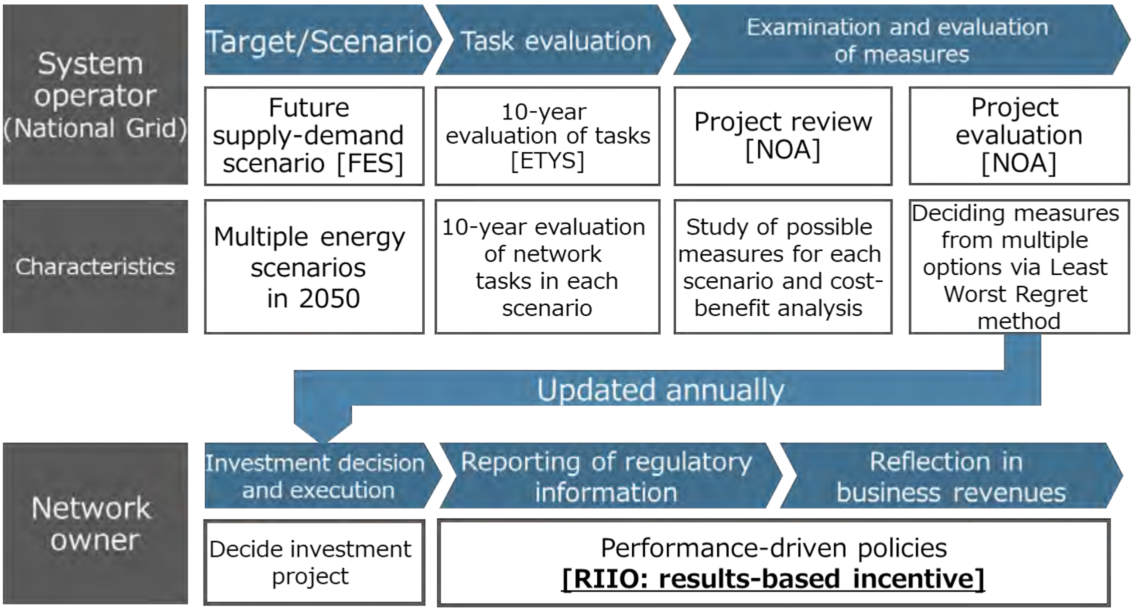
[34] TOTEX mechanism: CAPEX (capital expenditure) + OPEX (operating expenditure) = TOTEX. Part of the expenditure in excess of targeted TOTEX is returned to the operator as an incentive.

[35] See document published by Agency for Natural Resources and Energy, METI: https: //www.meti.go.jp/shingikai/energy_environment/denryoku_platform/pdf/005_03_00.pdf

[36] An analysis method that assumes the optimal countermeasure option for each scenario, and selects a combination of countermeasures that minimize opportunity loss even if the scenarios were to change.



Note: FES : Future Energy Scenario ETYS : Electricity Ten-Year Statement, NOA : Network Options Assessment
Source: OFGEM, RIIO-T1 Annual Report 2016-17, etc.

Figure 23: Relationship between scenario analysis and RIIO in the UK

(2) Construction of diverse systems suited to each local community and systems/policies for their complementation

The overall optimization of 3E+S for the entire energy system requires a mechanism that not only optimizes the energy use of each community including consumer resources but also achieves the targets of the entire society through the mutual complementation of local communities. For example, the mechanism can set targets by region, such as decarbonization rate, energy efficiency, and energy security, establishing a framework for local communities to examine and implement the method to accomplish these targets. The targets of each community are set as a whole to optimize the 3E+S of society.

The government should promote regional planning and implementation depending on the degree of goal achievement, for example, by providing incentives such as tax breaks and assistance, and strive for optimal balance between top-down decision-making and bottom-up planning and execution. Further discussions are necessary to flesh out these mechanisms, but such measures will encourage various stakeholders to invest in energy systems, which will promote a circular economy and support regional revitalization (Figure 24).

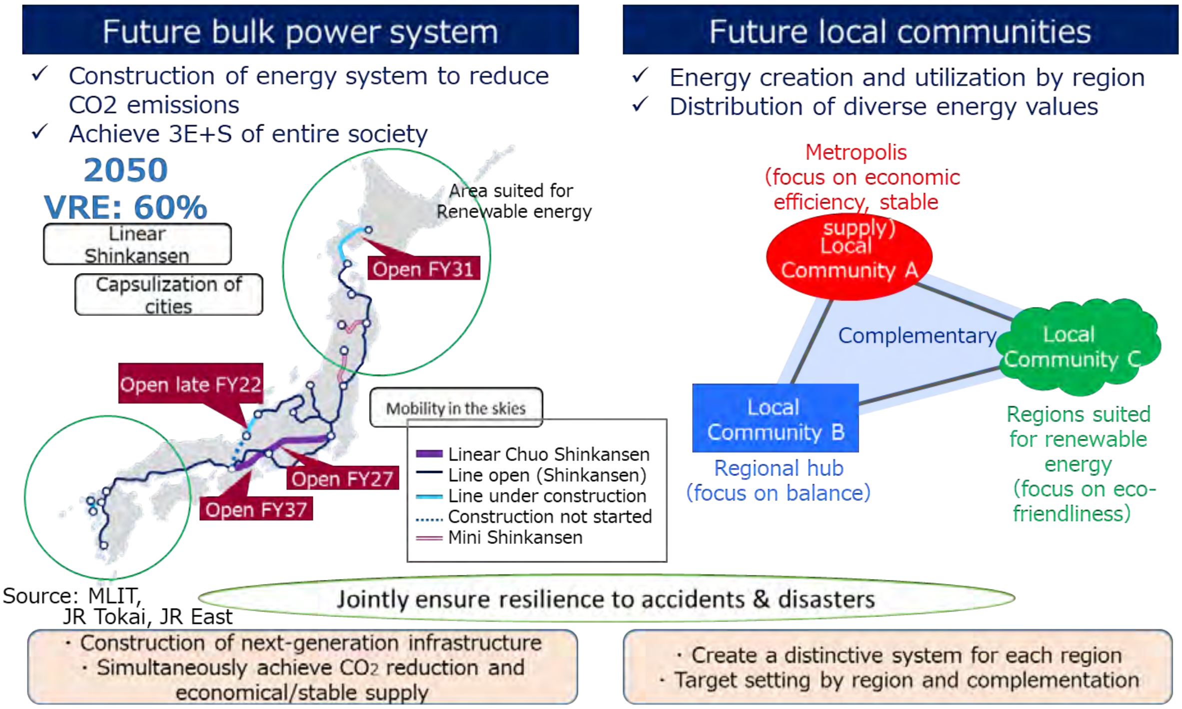


Figure 24: Bulk power systems and local communities

On the other hand, the local communities should implement energy strategies tailored to their regional characteristics. In this event, they must specifically consider the following items:

- An institutional framework that allows options suited to the needs of individuals and local communities[37] with regard to power quality (ex. voltage fluctuations, power outage time/frequency), and electricity rates per area
- Development of grid codes and wheeling rules to efficiently use distributed energy resources (DER) (ex. EV, storage battery, PV) in local communities
- Establishment of rules that allow participation from diverse players, such as local governments and local companies, in the power distribution business of the local communities
- A mechanism to support strategic investment in local communities, such as large-scale demonstration tests and tax measures for new initiatives

Local communities consider their energy strategies according to the characteristics of the community, such as population and industry. This process must be changed to one that entails an agile system design corresponding to repeated trial and error. Specifically, the following will be implemented:

[37] It is necessary to take measures that consider the characteristics and limitations of the electrical transmission and distribution networks.

- Study specific future directions and evaluation benchmarks with collaboration among industry, academia, government, and private sectors
- Construct an evaluation environment for energy systems in the local community and utilize it for discussion among stakeholders
- Horizontally expand the ministries cross -discipline review process and policy evaluation mechanism to other regions

6.3 Systems and Policies to Promote Innovation

(1) Promoting innovation and global roll-out of energy systems

To realize a long-term vision for 2050, industry, academia, and government must work together to promote various forms of innovation in both the local community and bulk power systems, and then globally roll out these technologies.

We expect advancements in the coordination and adjustment technology of distributed energy resources (DER) described in Chapter 3 to lead to long-term declines in power generation costs and the creation of new industries that utilize renewable energy as an energy source with zero marginal cost. For example, we expect the potential recruitment of agriculture and industries to utilize daytime energy surplus or large-scale hydrogen production through water electrolysis and renewable energy. In addition, other important developmental items for future decarbonization efforts include the formation of methane (methanation) via hydrogen and carbon dioxide synthesis, the conversion of electricity to heat and distributed energy storage, and Direct Air Capture (DAC)[38]. On the other hand, bulk power systems will undergo cooperation with multiple local communities, promoting enhanced efficiency and stable operation of decarbonized power sources such as nuclear power, and future implementation of decarbonization technologies such as CCUS.
To develop and implement future technologies in the highly uncertain field of energy, the pillars of industry, academia, and government must collaborate in pursuing a wide range of possibilities and encourage technological competition. In this way, they will be able to select and cultivate technologies that will truly become necessary to future global

[38] Technology to directly absorb carbon dioxide from the atmosphere. Presently, it is not used commercially because of the extraordinary cost needed for operation, but renewable energy, which has near-zero marginal cost, may pave a path to its realization.

markets. Various steps must be taken to achieve this, such as discussions among the stakeholders in industry, academia, and government, creation of a cross-discipline roadmap, and development of a platform for social decision-making.

Concurrently, the government should review procurement guidelines and procedures with reference to advanced overseas processes, consider standardization and de facto standard strategies to comply with global specifications, and take on the role of spurring Japanese industrial growth and overseas expansion. In addition, the utilization of international finance and CO_2 credits are also effective measures for the same goal. Private companies will globally roll out the energy systems built in Japan[39] and contribute to the international community. In addition, they will pursue continuous improvements by repatriating the knowledge obtained in overseas markets to enhance the domestic system. Universities promote the development of internationally competitive technology and use academic findings to improve the quality of institutions and policies. Furthermore, human resource development is also essential (Figure 25).

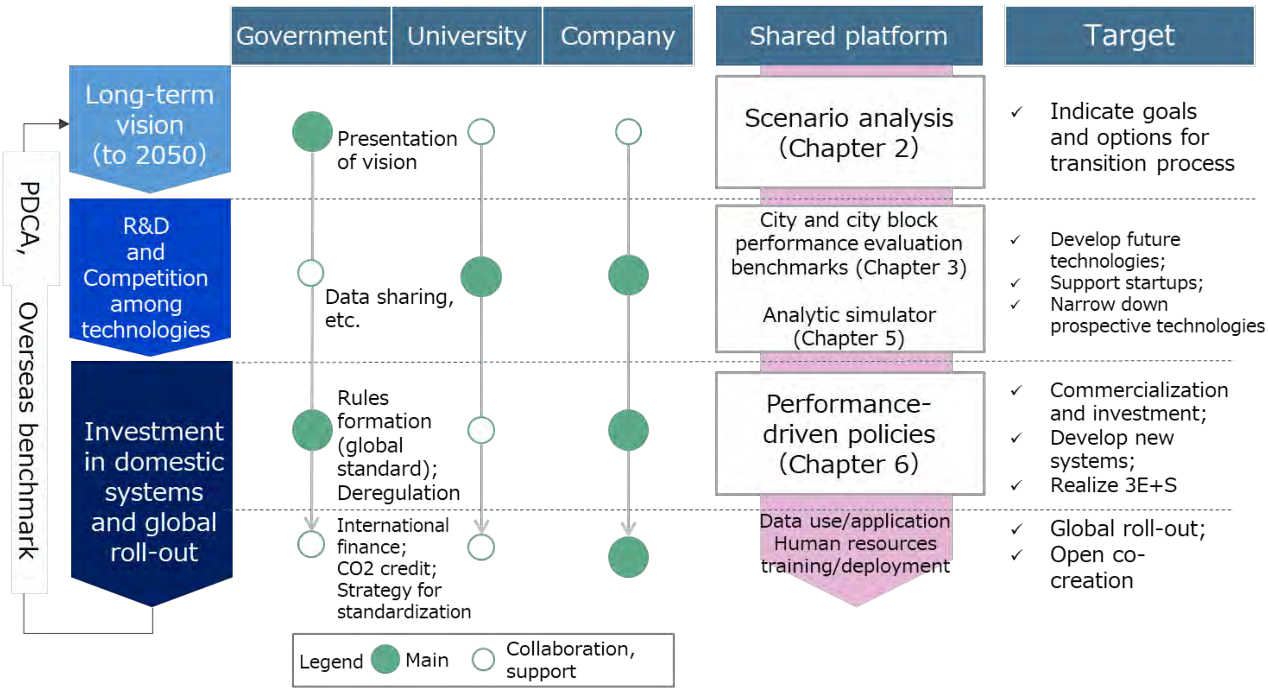


Figure 25: Cooperation between industry, academia, and government; shared platforms

[39] This refers not just to energy network technology but the entire energy system, including power sources such as renewable energy and clean coal, and consumer-level resources such as heat pumps.

(2) Flow of funds to yield innovation

The government must establish a flow of funds mechanism to promote investments in innovation for the transformation of energy systems and creation of industry. Currently, ESG investments that emphasize environmental and social values are spreading rapidly around the world. It is imperative to promote systemic reinforcement to guide such investments into long-term R&D and capital expenditures. For example, it may be effective to use Green Bonds[40] and Sustainability Bonds[41], where global issuance amount has spiked in recent years. The formulation of uniform issuance criteria and international rules to quantify the environmental and social values generated by funded projects will be necessary to improve market transparency and credibility. Japan will also be expected to contribute by developing conforming rules[42].

In addition, the value of energy will diversify away from the current kWh, kW, and ⊿kW to those that will include environmental and social significance. The real-time trading of these values will also be made possible. It will be important to use such market systems to increase the flow of funds and create a virtuous cycle in which energy consumers and suppliers will reinvest in added value. Specifically in Japan, the deployment of renewable energy will lead to decreased imports of oil, coal, and other foreign resources, along with a decline in national capital outflow. In the long run, we believe it will also be important to utilize surplus funds for energy conversion and industrial development.

(3) Establishment of a data distribution system for innovation and cyber security

The source of value in Society 5.0 is data; the establishment of a data distribution system must also be promoted from an institutional perspective. The government must establish rules to protect personal privacy and corporate trade secrets, such as smart meter data, and develop a data distribution environment rooted in reliability. The establishment of a data distribution system assumes the sharing of information across industrial boundaries and the interconnection of devices, but requires a high standard of security for infrastructural control to assure safety. In addition to measures driven by private-sector companies, the national government should formulate and implement relevant policies, taking the following points into consideration:

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[40] Green Bonds are bonds issued specifically to raise funds for projects that contribute to environmental sustainability.
[41] Sustainability Bonds are bonds used to finance or refinance a combination of both Green Projects (that contribute to environmental sustainability) and Social Projects (that address and mitigate specific social issues).
[42] The International Organization for Standardization (ISO) promotes the standardization of evaluation methods and information disclosure items related to the environmental value of a project.

- Strengthen security measures for the entire energy system in response to ever-expanding and increasingly sophisticated security threats.
- While making systems specifications open for mutual interconnectivity, adopt the concept of “security by design” that ensures the ground-up security of the entire system from design to external connectivity.
- Implement mission assurance[43] while establishing organizational governance, such as clarification of security policies around procurement, verification of evidence, and development of organizational units that handle operational security.

[43] Mission assurance: A process whereby business managers, with system managers, analyze the risks blocking the functions and services of key infrastructures, provide information to management, and receive comprehensive judgment.

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, society will need to 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. On the basis of this, we consider short-term scope to cover 5 to 10 years, medium-term scope to cover 10 to 20 years, and long-term scope to cover 20 to 100 years. 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. Furthermore, industries should develop a system to properly receive and utilize the talent entering the sector after such interdisciplinary education.

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 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 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, the formulation and implementation of a multi-scope, energy systems-related strategy 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. To secure the personnel suited to a range of functions in a changing energy system, it is desirable to secure a pool of veteran personnel beyond the boundaries of individual companies. At the same time, the standardization of technological standards (which currently vary by company) is important with respect to securing personnel in an aging population. In local communities that strive for new direction, it is especially important to utilize veteran personnel as innovators to link industry, academia, and the government.

Chapter 8: Conclusion

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

- Attempts to rebuild energy systems assuming the **coexistence of local communities and bulk power systems** (Chapter 1)

  In Society 5.0, individual lifestyles will take center stage, building energy systems that are distinctive to each local community. 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 take on the role of optimizing 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 new technologies to facilitate a coordination mechanism to integrate these distributed energy resources.

- **Flexible decision-making from a medium-to-long-term perspective** to reform the structure of the whole society (Chapter 2)

  Amid mounting mid-to-long-term uncertainty caused by global economic and social changes and technological innovations, it is important to assume and prepare multiple long-term energy scenarios to realize Society 5.0. Technology development and facility deployment to the energy infrastructure must be considered in units 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.

- **Various stakeholders participate** to **create new values** for the energy systems, supporting local communities (Chapter 3)

  Local communities must strive for a new direction: technological innovation and system upgrades to create, distribute, and trade unique values amid the diversification of energy values. For example, areas well-suited for renewable energy should strive to become communities that utilize surplus power to foster local industries, in addition to developing stabilization measures for the electricity system. They should create new services and businesses by establishing a mechanism to publicly share information among various infrastructural services, including not only the traditional services of electricity, gas, and water but also ICT, transportation, and logistics.

- Bulk power systems serve to **connect local communities** within the **important role of optimizing 3E+S** (Chapter 4)

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. In order to discuss the ideal form of the bulk power system, a platform will be built to evaluate the energy systems of the entire society with a focus on electric power. Industry, academia, and government will collaborate to develop and share analytical tools and standard data. 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 technology that will digitally connect the bulk power system to the local community, and globally roll out the technology and experience.

- **Conceptual design** of the evaluation platform and data sharing (Chapter 5)

Evaluation platform users will be defined, use cases will be assumed and extracted, 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. In addition, the evaluation platform needs continuous improvements and updates, requiring an appropriate operator to be specified.

- Develop **systems and policies rooted in diversity** to promote the transformation of local communities and bulk power systems (Chapter 6)

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 review systems and policies to promote the restructuring of bulk power systems and local communities. For the former, we propose simultaneously accelerating investment and efficiency through performance-driven policies. For the latter, we build a system 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 in Chapter 5, we 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 (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.

Figure 26: Overview of energy systems to support Society 5.0

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Team Members of Proposal Version 2 (as of March 31, 2019)

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WGs refer to the following working groups:

WG0: overall vision; WG1: evaluation platform; WG2: systems and policies.

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

Appendix

【Appendix 1】 Quantitative verification of long-term energy scenarios using the technology selection model

1. Overview of the Technology selection model

The technology selection model, a function of the energy and economic model, is a tool that can quantitatively analyze the various issues of energy policy. To date, a number of methods have been proposed for energy and economic models, with each having unique features. In this section, we attempt to quantify long-term scenarios through 2050 by focusing on technology selection models that can verify each scenario by back-casting. The technology selection model is characterized by its ease of individually interpreting technical fields, as well as being able to specify the routes that satisfy preconditions via back-casting. On the other hand, its disadvantages include not being able to express the relationship with economic sectors other than the energy sector and requiring a large amount of data and time for calculation.

The energy system research laboratory under the leadership of Professor Yasumasa Fujii and Assistant Professor Ryoichi Komiyama of the University of Tokyo (Fujii-Komiyama Lab) used the model developed by Yasuaki Kawakami to show the results of testing the four scenarios described in this proposal with specific preconditions. As mentioned above, the technology selection model does not show relevance to economic sectors other than the energy sector; therefore, we will not discuss energy costs, but rather will outline the technical approach towards decarbonization and the selection of issues pertaining to electricity systems.

2. Setting prerequisites for the technology selection model

Prerequisites of the technology selection model are mostly based on Kawakami's report[44]. We assume the standard energy system shown in Figure A1-1 and set the energy carriers for the system and the technologies to convert, transmit, distribute, and consume the energy. The main preconditions are as follows:

[44] Kawakami, Y. (2018). Doctoral dissertation at the University of Tokyo.
Kawakami, Y., Komiyama, R., and Fujii, Y. (2018). IEEJ Transactions on Power and Energy, Vol.138, No.5, pp.382-391.
Kawakami, Y., Komiyama, R., and Fujii, Y. (2018). JSER Journal of Energy and Resources, Vol.39, No.4, pp.10-19.

(1) The final consumption of energy occurs according to the category of demanded energy service shown in Figure A1-1.

(2) The energy supply-demand is balanced in intervals of 10 minutes. Demand is determined endogenously by the operating status of energy services.

(3) We assume the maximum capacity for new thermal power plants to be 10 GW. Nuclear power is tested 40 years after the start of operation; no expansion is made after 20 years of extended operation. The maximum capacity of hydropower generation in 2030 is 22GW for general hydropower and 27.5GW for pumped-storage hydropower.

(4) The VRE utilization rate is estimated from actual values based on weather data taken at a 10-minute interval. This is used in the future.

In the verification of multiple scenarios in Chapter 2, we considered the following assumptions. The 20-year period spans 2030 to 2050.

(A) CO_2 emissions in 2050: 238 Mt- CO_2 (-80% vs FY 2013)

(B) CO_2 emissions in 2050: 417 Mt- CO_2 (-65% vs FY 2013)

(C) CO_2 emissions in 2050: 691 Mt- CO_2 (-40% vs FY 2013)

(D) CO_2 emissions in 2050: 238 Mt- CO_2 (-80% vs FY 2013) and VRE 50% or less

The decarbonization technology progresses in the following order: condition (C), (B), (A). Decarbonization technology progresses the same for condition (D) as it does for condition (A), but VRE deployment is equal to the stagnant case.

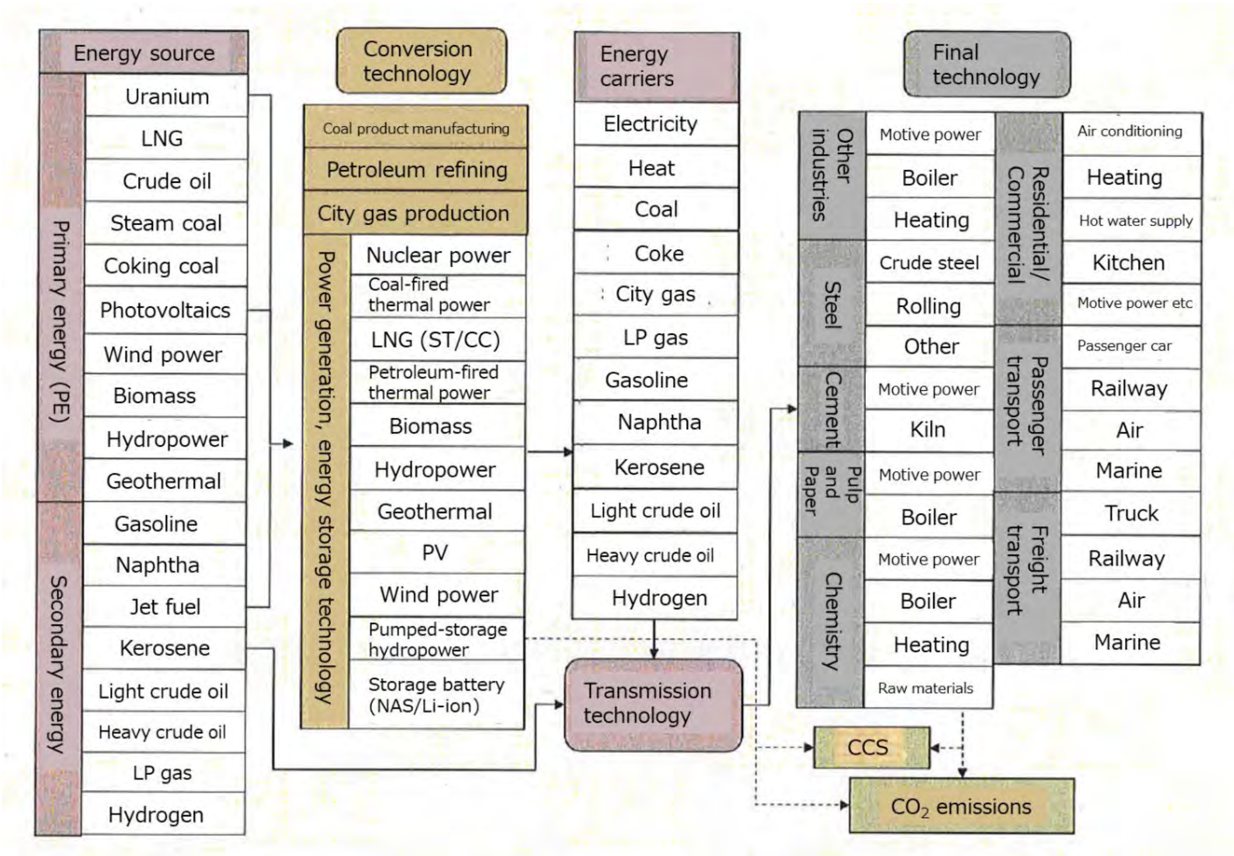


Figure A1-1: Standard energy system

3. Tests accompanying the CO_2 reduction ratio

Figure A1-2 shows the power generation profile in the Kanto region in May under conditions (A) to (D). In condition (C) 691Mt-CO_2 @ 2050, the power supply roughly follows the demand curve, and the VRE surplus during daytime is mainly used to charge EVs. The nighttime VRE shortage is covered by LNG thermal power. In condition (B) 417Mt-CO_2 @ 2050, there is remarkable PV surplus when it is sunny, but the introduction of LNG thermal power is permitted at night, when VRE is insufficient. In condition (A) 238Mt- CO_2 @ 2050, the power is a surplus unless the weather is stormy, and the daytime surplus is distributed to EV charging, storage battery, and heat utilization (FIRES). Power supply during stormy weather is almost entirely limited to non-fossil fuels such as storage batteries, hydrogen, and ammonia. In condition (D) 238 Mt- CO_2 @ 2050 and VRE 50% or less, VRE becomes a surplus when sunny, and a storage battery is used to store energy. On the other hand, fossil fuel-based power generation cannot be used even during stormy weather, and energy supply is mainly supplemented using biomass. The series of simulation results show that innovations in stored energy and decarbonization technology for VRE deployment are indispensable for decarbonization.

Figure A1-3 shows the breakdown of CO_2 emissions. The progressing CO_2 reduction will decrease the ratio of emissions caused by power generation and becomes 0.6% in case (A) 238 Mt- CO_2 @ 2050. In other words, the advancement of electrification on the demand side is effective for decarbonization.

Figure A1-4 shows the transition of power generation by case. The ratio of VRE to total power generation was (A) 59%, (B) 35%, and (C) 20%. In addition, the total generated power had the tendency to increase in cases where the introduction of VRE reduced CO_2 emissions.

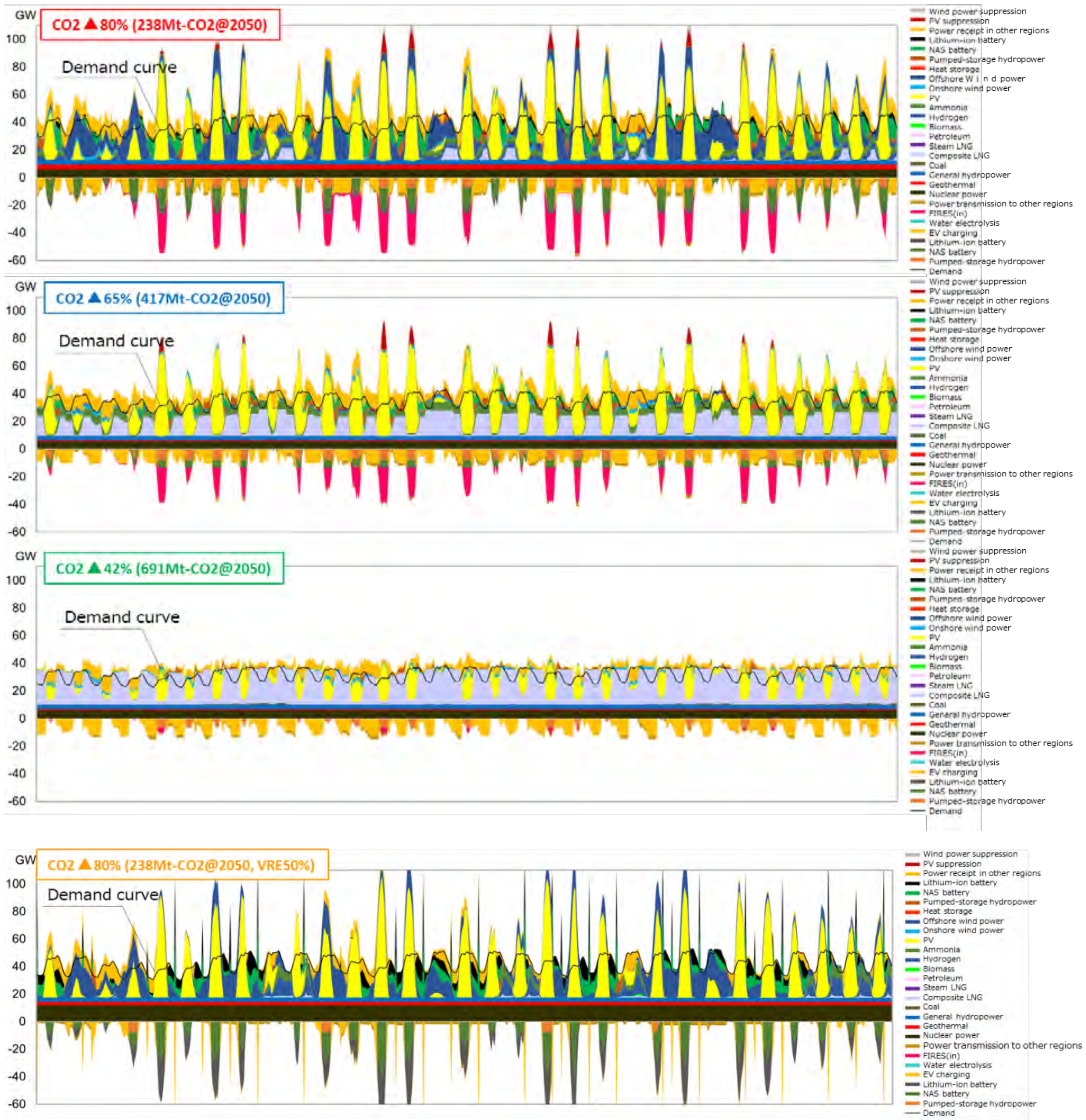


Figure A1-2: Energy supply-demand management corresponding to CO_2 reduction amount (May, Kanto Region)

In (A), VRE monotonously increases; it absorbs this fluctuation using heat and stored energy to achieve an 80% reduction in CO_2. On the other hand, in condition D (stagnation of VER deployment), non-fossil fuel power generation such as hydrogen and biomass is selected entailing time for construction; it is critical to introduce this type of output-stable renewable energy early on.

Figure A1-5 shows the breakdown of power generation to total energy consumption. While energy consumption decreases because of improvements in operational efficiency such as energy saving, electrification rates in 2050 advances to 37% in conditions (A) and (D).

4. Summary of scenario quantification using the technology selection model

A) Energy supply-demand management

The supply-demand balance is maintained until CO_2 reduction is about 50%; the VRE surplus is used for EV charging. As decarbonization progresses further, a VRE surplus regularly occurs during sunny weather, requiring various types of stored energy, including FIRES. When VRE deployment stagnates, biomass and hydrogen are selected as non-fossil fuel sources to reduce CO_2 emissions. In addition, the energy supply during storms is mainly shouldered by biomass.

B) The power generation sector during -80% reduction in CO_2 emissions

In an energy system with an -80% reduction in CO_2 emissions, the amount attributed to the power generation sector will be less than 1%. The ratio of renewable energy will reach 77% and VRE will become 60%. Energy-saving efforts will reduce energy consumption. The electrification rate will reach 45% in 2050.

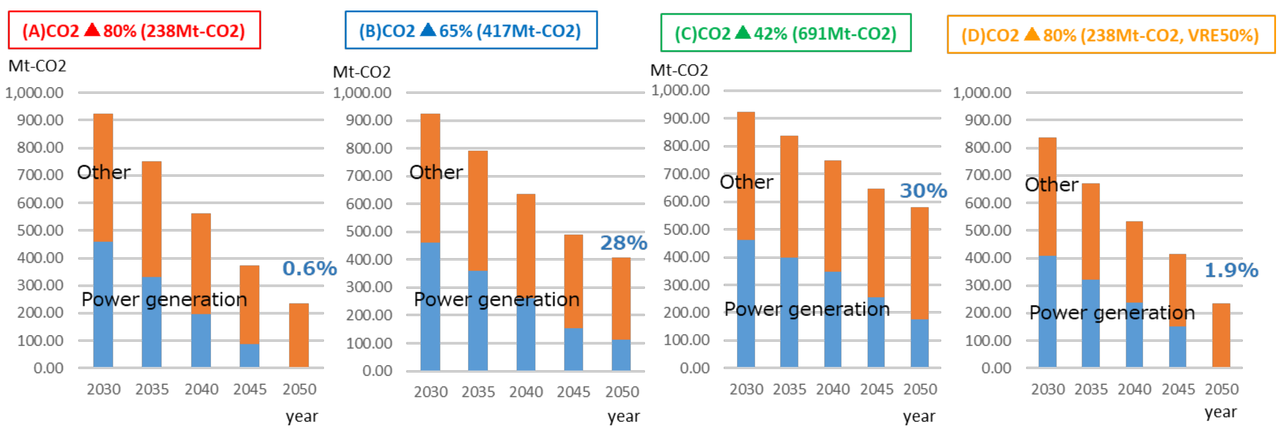


Figure A1-3: Ratio of CO_2 emissions in the power generation sector vs emissions in all sectors

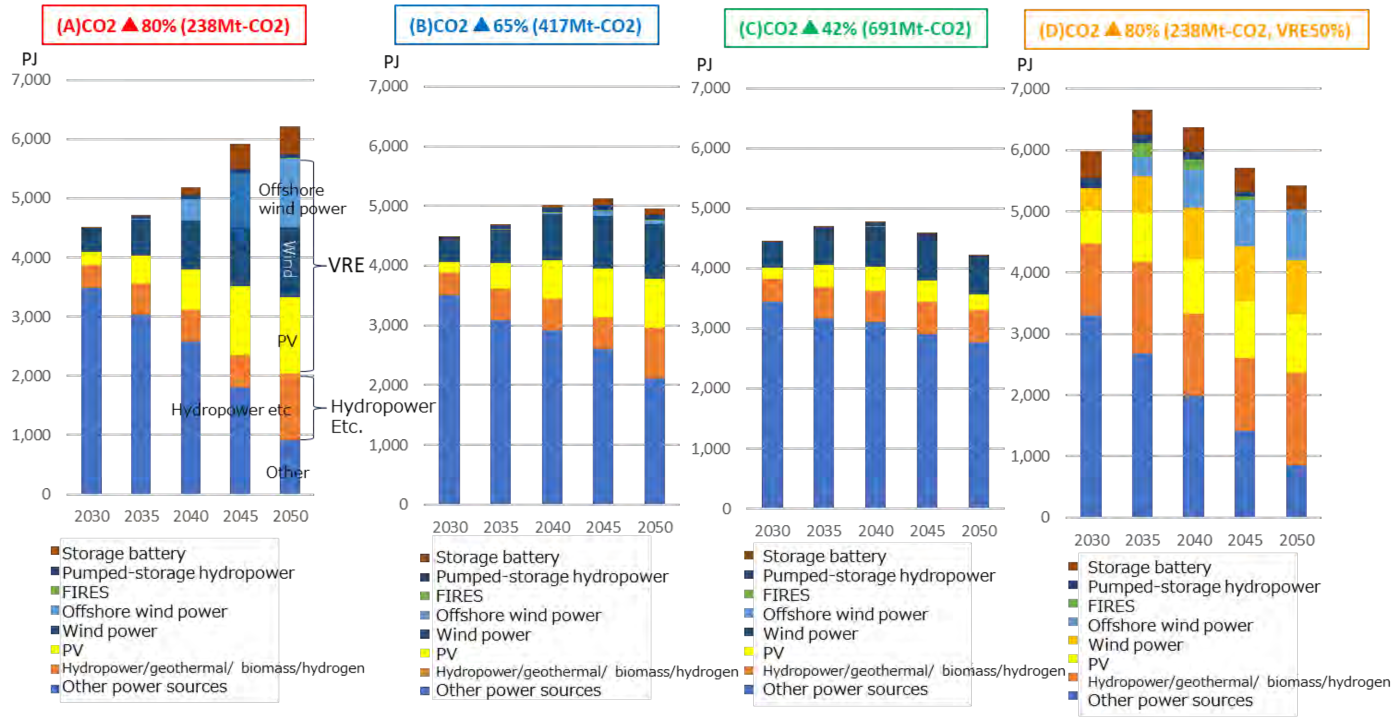


Figure A1-4: Generated power in power generation sectors corresponding to each case

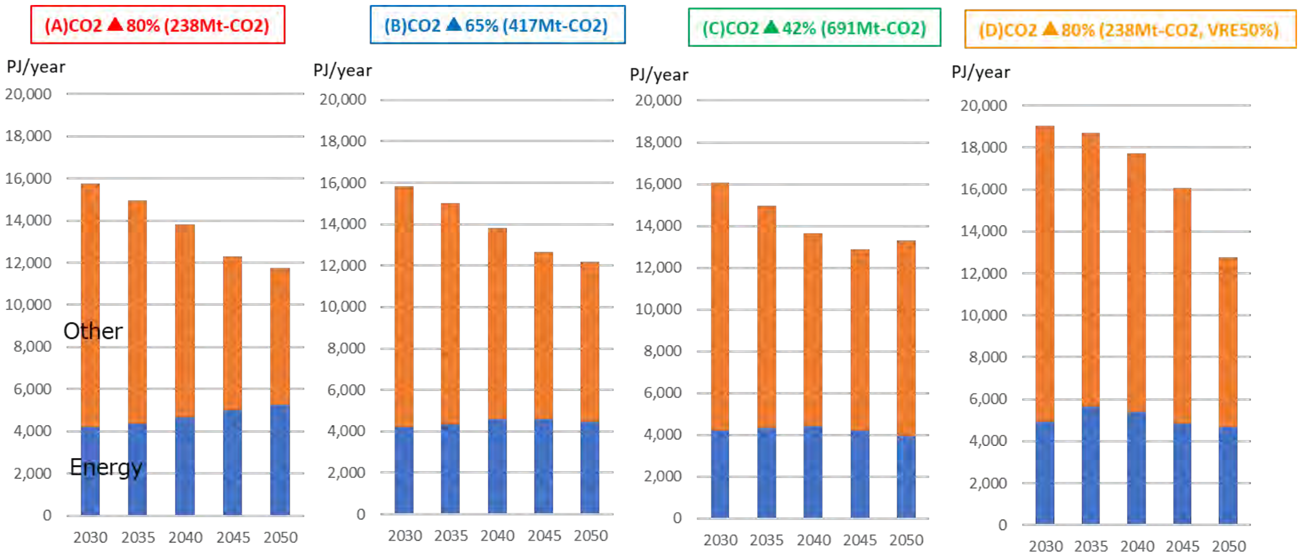


Figure A1-5: Ratio of the energy sector to energy consumption corresponding to CO_2 reduction

【Appendix 2】Use cases and information/data needed for evaluation by stakeholders

To actualize the evaluation platform, we extracted the use cases utilized for evaluation by various stakeholders and summarized the necessary data for evaluation in each use case as shown in Tables A2-1 and A2-2. The table shows analytical tools and evaluation benchmarks used in each use case, along with the input data used for analysis. The “shared data” for the input is made up of “actual/performance values,” which are determined by equipment configuration, and “measurement value,” which is measurement data accumulated thus far. In addition, “individually prepared data sample” is a value assumed based on scenario and is composed of “future assumptions” such as changes in system configuration or renewable energy deployment, and “normalized value” assuming demand and weather.

Table A2-1: Information/data usage map (1/2)

Use case					#	1	2	3	4
Objectives	Content					Vision/policy proposals	Proposal of control, operation, and rules of power systems	Evaluation of electricity wheeling	Feasibility evaluation of renewable energy generation
Objectives	Stakeholders					Citizens/universities/ think tanks /media /legislature/ regulatory agencies	Universities/research institutes/ regulatory agencies	Universities/regulatory agencies/power transmission & distribution co	Wind energy co/photovoltaics co/power transmission & distribution co
Objectives	Example of use					・Examine and propose future strategies for environment and energy ・Examine renewable energy deployment and incentive systems	・Propose new management methods for power system (voltage, frequency, maintenance of stability, etc.) ・Propose operational standards/rules	・Examine wheeling fees for future power systems ・Estimate congestion of power transmission/ distribution lines caused by wheeling ・Plan transmission line facilities	・Estimate annual power generation and output control amounts ・Calculate interconnection costs
Objectives	Analytical engine			Supply reliability evaluation		✓	✓	–	✓
				Supply-demand management plan (UC, ELD)		✓	✓	✓	–
				Voltage stability		✓	✓	✓	✓
				Frequency stability		✓	✓	–	–
				Synchronization stability		✓	✓	✓	✓
				Transient phenomenon		–	✓	–	✓
Output	Evaluation benchmark (KPI)			Fuel cost (annual improvement)		✓	–	✓	–
				CO2 emissions (eco-friendliness)		✓	–	–	–
				Renewable energy generation and output suppression		✓	✓	–	✓
				Cost of renewable energy measures		✓	✓	–	✓
				Value of ancillary services		✓	–	✓	–
Input	Shared data	Actual values/performance values	Impedance map	Detailed power system ≧ 275kV	1	○	–	○	○
				Detailed power system ≧ 66/72kV	2	–	–	○	◎
				Power distribution system in a specific area	3	–	○	○	○
			Generator	Generation capacity and location	4	◎	◎	○	–
				Control and dynamic characteristics of power plant systems	5	○	–	–	–
				Fuel consumption characteristics	6	○	○	–	–
			Renewable energy	Power generation results	7	○	○	○	–
				Control and dynamic characteristics of machine systems	8	○	–	–	○
			Demand	Demand (≧ 157kV)	9	○	○	–	–
				Demand (66kV)	10	–	–	–	○
				Voltage and frequency characteristics	11	○	○	○	○
				Dynamic characteristics	12	○	–	–	○
			Area	LFC control system	13	○	○	–	○
				Frequency and control of interconnected line	14	○	○	–	○
		Measured values	Power system	Power flow in a transmission line (bulk power system)	15	○	○	○	○
				Power flow in a transmission line (regional system)	16	–	–	○	○
			Generated power/ demand	Smart meter	17	–	–	–	–
				Power from distributed generation	18	○	–	–	○
	Example of individually prepared data	Future assumptions		Changes in system configuration	19	○	–	–	○
				Renewable energy capacity	20	◎	○	○	○
		Normalized value		66kV demand	21	–	–	○	○
				Future weather	22	○	–	–	○

Table A2-2: Information/data usage map (2/2)

Use case					#	5	6	7	8
Objectives	Content					Impact evaluation of the interconnection of distributed power supply	Feasibility evaluation of adjusting capacity and ancillary business	Feasibility evaluation of P2P energy trading	Assessment of EV charging infrastructure
Objectives	Stakeholders					Universities/power transmission & distribution co	Local energy co/power plant /power transmission & distribution co	General consumers/ aggregators/ power transmission & distribution co	EV companies/city & city blocks/power distribution companies/local government
Objectives	Example of use					・Evaluate stability and reliability during system interconnection	・Forecast hourly adjusting capacity (kW, △kW) ・Quantitatively evaluate the stability and reliability contributed by provision of adjusting capacity	・Analyze future business scenarios ・Test suitability of transmission and distribution network usage costs through P2P trading	・Assess (energy quality, economic effects) to apply for development of charging infrastructure ・Estimate overload and voltage fluctuation at interconnection points ・Calculate the effects of charge/discharge shifts and reactive power control
Objectives	Analytical engine			Supply reliability evaluation		✓	–	✓	–
				Supply-demand management plan (UC, ELD)		–	–	✓	–
				Voltage stability		✓	✓	–	✓
				Frequency stability		✓	✓	–	–
				Synchronization stability		✓	✓	–	✓
				Transient phenomenon		✓	–	–	–
Output	Evaluation benchmark (KPI)			Fuel cost (annual improvement)		–	–	–	✓
				CO2 emissions (eco-friendliness)		–	–	✓	–
				Renewable energy generation and output suppression		✓	✓	✓	–
				Cost of renewable energy measures		✓	✓	✓	✓
				Value of ancillary services		–	✓	✓	✓
Input	Shared data	Actual values/performance values	Impedance map	Detailed power system ≧ 275kV	1	○	–	–	–
				Detailed power system ≧ 66/72kV	2	◎	○	○	○
				Power distribution system in a specific area	3	◎	○	○	◎
			Generator	Generation capacity and location	4	○	○	–	–
				Control and dynamic characteristics of power plant systems	5	–	–	–	–
				Fuel consumption characteristics	6	–	–	–	–
			Renewable energy	Power generation results	7	○	○	○	–
				Control and dynamic characteristics of machine systems	8	○	○	–	–
			Demand	Demand (≧ 157kV)	9	○	–	–	–
				Demand (66kV)	10	○	–	○	–
				Voltage and frequency characteristics	11	○	○	○	–
				Dynamic characteristics	12	–	–	–	○
			Area	LFC control system	13	○	○	–	–
				Frequency and control of interconnected line	14	○	○	–	–
		Measured values	Power system	Power flow in a transmission line (bulk power system)	15	–	–	–	–
				Power flow in a transmission line (regional system)	16	○	○	○	–
			Generated power/ demand	Smart meter	17	–	–	○	○
				Power from distributed generation	18	○	○	○	○
	Example of individually prepared data	Future assumptions		Changes in system configuration	19	○	–	–	–
				Renewable energy capacity	20	○	–	○	–
		Normalized value		66kV demand	21	○	–	○	○
				Future weather	22	○	–	○	–

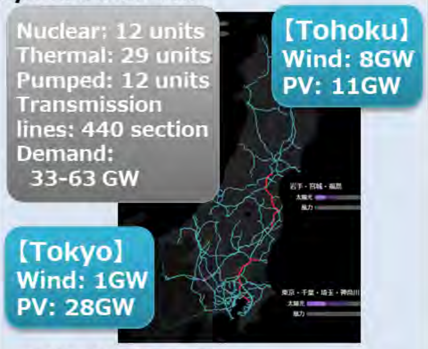
【Appendix 3】Analytical method and model for simulator evaluation

We explain the analytical method and model used in the simulation in Section 5.4. To study the system configuration corresponding to the expansion in VRE deployment, we modeled it as closely as possible to the actual configuration. In this proposal, we traced the power transmission line using Google maps to create the power system map. We also included many assumptions, such as the use of the IEEJ standard model as the generator model. Data sharing is a prerequisite for a detailed study. We implemented the power generation plan UC in consideration of the supply-demand balance and standard reserve of 8%, then calculated the VRE output control amount by eliminating surplus power and overloads on the line and transformer, ensuring stability.

Figure A3-1 shows the analytical method and model, as well as the assumptions and constraints.

Aim

Accurately model the actual system configuration to support the evolution of the power system and VRE



※Hokkaido case
2-4 GW surplus power generated for 3-5.5 GW demand
(0.9 GW transmitted to Honshu)
→ HVDC transmission to demand areas or output suppression needed

Simulation Method

UC • Supply-demand balance • Reserve capacity ⇒ **Calculate RE output suppression**: **Eliminate power surplus** ⇒ **Eliminate overload** Lines/ transformers in ~440 locations ⇒ **Maintain stability** Evaluate ground fault failures ~130 locations ⇒ **Evaluate benefits** • Economic • Environmental

#	Item	Assumptions and Constraints
1	Power generation	• Continuous parallel operation of nuclear/coal power • Determine driving power on the condition of reserve capacity (LFC 3%) (30% minimum output) • Apply IEEJ/ETRA model for AVR/PSS/governance
2	VRE	• FRT: Simulated by grid interconnection rule • Output that considers normalizing effects and weather such as sunny/cloudy (right table) PV generation prob. 18+32/2=34%→
3	Power system	• Assumption 2030 (OCCTO plan); model≧275kV • Condense ≦ 66kV, simulate 20% load with IM*1)
4	Pumped-storage hydropower	• Use all 13.2GW for VRE measures
5	Failures	• 3LG-O on the main line (assume ~130 locations)

Sunny	18%
Sunny/ Cloudy	32%
Cloudy/ rain	50%

	Wind	PV
Tohoku	71%	93%
Tokyo	34%	79%

*1) See analytical power system model by WECC (North America)
UC: Unit Commitment , AVR: Automatic Voltage Management, PSS: Power System Stabilizer, RE: renewable energy;
IM: Induction Motor, WECC: Western Electricity Coordinating Council, FRT: Fault Ride Through

Figure A3-1: Analytical method and model