Proposal

Toward Realizing Electricity Systems to Support Society 5.0

(Ver. 1)

April 18, 2018

Hitachi-UTokyo Laboratory

Introduction

Large-scale integration of renewable energy sources, development of ICT, globalization, changes in people's values and other factors in recent years have caused knowledge and value creation processes to change significantly, leading to the advent of an era of major reforms with drastic changes in economic and social frameworks and industrial structures. Japanese government has announced its "Society 5.0" program which to create new values meeting such economic and social changes, to share a future vision toward a super-smart society bringing about a good life, and to solve social issues ahead of the rest of the world.

The University of Tokyo, a national university corporation, has combined and produced multidisciplinary research results to solve issues and contribute to policy-making based on its belief that solving complicated global issues facing our society necessitates wide-ranging knowledge combination and collaborative knowledge creation from a global perspective instead of academic pursuit in a single discipline. In fact, since its foundation, the University of Tokyo has developed academic centers that fuse Western and Eastern cultures. Succeeding this tradition, the University envisages the establishment of a Global Base for Collaborative Knowledge Creation that will attract a range of people and link the pursuit of knowledge with the utilization of knowledge. This Base will work on large-scale issues and seek to realize industry-academia collaborative creation with an enhanced function for creating new social values by having the industry and the academia share a direction on an organizational level and proactively generate synergy effects.

Hitachi, Ltd. (hereinafter, "Hitachi") is implementing social innovation businesses, combining its infrastructure technologies that it has developed over many years and advanced information technologies. Going forward, Hitachi seeks to create new values leveraging digital technologies to accelerate collaborative creation with its customers and partners and implementation of open innovations and provide optimal solutions for social issues.

The University of Tokyo and Hitachi founded Hitachi-UTokyo Laboratory on June 20, 2016, in the campus of the University of Tokyo based on the new industry-academia collaborative creation scheme, to combine their initiatives and thereby to create businesses and innovations toward realizing Society 5.0 that will realize the well-being of humanity.

As part of its activity areas, the Laboratory considers energy systems, especially electricity systems that support a data-driven society in Society 5.0. A shift will inevitably occur from the conventional electricity systems based on large-scale power sources to new systems including expanded integration of renewable energy sources, diversification, digitalization, electrification and motorization. Against this backdrop, it seeks to identify technological, policy and institutional issues concerning future electricity systems supporting Society 5.0 and have awareness of the issues shared among related parties while considering domestic and overseas situations. The laboratory will publish results of these initiatives as its proposals.

Directions of discussions

In considering electricity systems supporting Society 5.0, discussions have developed around the following three major directions.

A) Formulating a vision for Society 5.0

Energy systems should be restructured based on the assumption that they will be important infrastructures for changing social frameworks and individual life styles toward the future in addition to the conventional energy supply perspective. While leveraging Japan's high credibility, technological skills and human resources that have been developed so far, we will seek to establish Society 5.0 that creates new industries and employment and thereby to contribute to the international society with the new vision and technologies.

In discussing what should be done toward industrial structural transformation, we should keep in mind three different timescales: short-, medium- and long-term. Energy creates extremely significant social impacts and legacy. Transformation of energy structures takes time. Therefore, short-, medium- and long-term transformations should be considered in terms of, respectively, 5 to 10 years, 10 to 20 years and 20 to 100 years.

In the world with increasing uncertainties, strategic implementation of various initiatives necessitates formulation of medium- and long-term visions toward 2030 and then 2050 and discussions of systems and policies (social systems) toward realizing those visions based on multiple scenarios. Also, a range of technical options should be prepared. Technical development that is critical for medium- and long-term scenarios involves significant uncertainties that could not be handled only with market principles and, therefore, necessitates strategic investment from national and global perspectives.

B) Open social decision-making framework

Discussing and sharing a vision for energy systems across the society necessitates development of an open platform for transmitting and sharing quantitative and objective information and of a decision-making framework based on it. Based on industry-academia-government cooperation, information sharing among stakeholders should be promoted, and data and tools relating to energy systems should be shared to the possible maximum extent. Such open discussions would also encourage healthy competition among energy systems.

Formulating a social agreement concerning energy systems requires not only responses to issues currently occurring but development of a mechanism for discussing and considering various directions from broad perspectives.

C) Cross-segmental human resources development

For development of energy systems supporting Society 5.0 and creation of an infrastructure industry positively contributing the global society, it is imperative to understand scientific/technical innovations, social systems and economic mechanisms in an integrated manner.

It is necessary to promote initiatives beyond boundaries of industries, academic disciplines, and generations based on industry-academia-government cooperation and to develop individuals capable of discussing values from multiple angles.

Formulate a vision for Society 5.0	• Conduct discussions based on multiple scenarios and prepare a range of technological options to realize medium and long-term visions toward 2030/2050; and • Leverage Japan's high credibility, technological skills and quality human resources; • Continuously invest into technological development based on the medium and long-term scenarios from a national perspective; • Contribute to the international society with established technologies
Open social decision-making framework	• Develop an open platform for transmitting and sharing quantitative and objective information and a decision-making framework based on it for the purpose of sharing a vision for energy systems; • Promote healthy competition among energy systems based on open discussions; and • Share data and tools to the possible maximum extent for to formulate a social agreement.
Cross-segmental human resources development	• Develop individuals capable of discussing values from multiple angles, for it is imperative to understand scientific/technical innovations, social systems and economic mechanisms in an integrated manner; and • Promote initiatives beyond boundaries of industries, academic disciplines, and generations based on industry-academia-government cooperation

Figure: Directions of discussions

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Toward Realizing Electricity Systems to Support Society 5.0

Chapter 1: Future vision for energy systems

1.1 Overview of energy systems

The following is an overview of and future vision for energy systems.

In Society 5.0, individuals will play the central roles in daily living, and energy systems will be developed that reflect local communities' characteristics. Along with drastic changes in economic, social and industrial structures, energy systems suitable for the respective local communities will be redeveloped based on mutual linkage and coordination among various infrastructures supporting the local communities including not only electricity, gas and water but ICT, automobiles and logistics. Values concerning the use of energy by individuals will be diversified. They will be measured not only in terms of energy cost charged by quantity consumed but also in terms of environmental friendliness including CO_2 reduction and local resources preservation as well as convenience and comfort in daily living. In addition to these trends, energy consumption will be increasingly electrified and motorized. Furthermore, power electronics technologies supporting power utilization will disseminate. In the future, utilization of secondary energy will commence that can be stored in large quantity and for a long period. Along with digitalization, energy consumption behaviors will become more flexible than ever before in terms of both time and quantity. Given such energy demand characterized with improved controllability, data will play important roles. A new society emerge where new values and services are provided in a fused manner (Fig. 1).

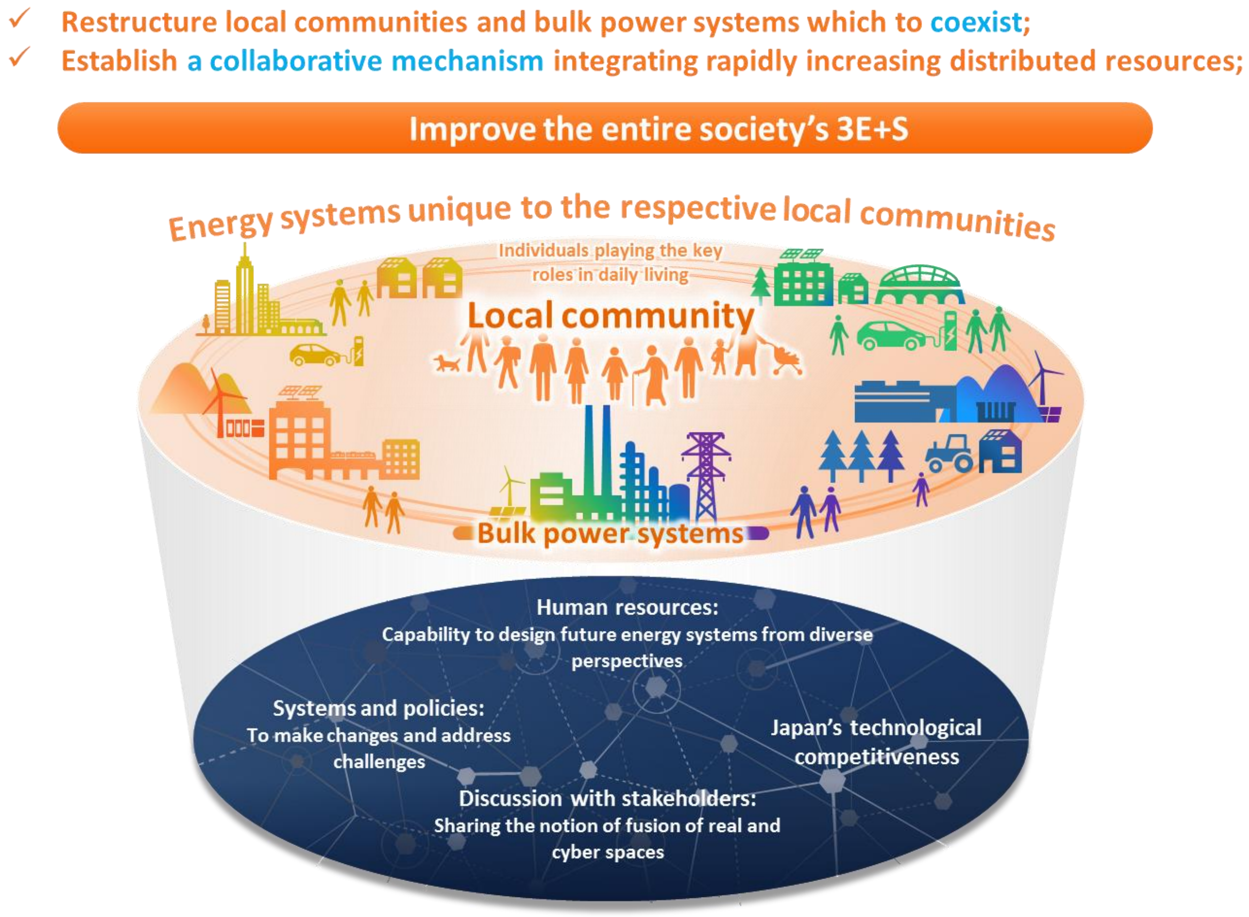

Fig. 1: Overview of energy systems supporting Society 5.0

Changes in the local communities necessitates major reforms of, especially, electric power supply systems. Conventional power supply has been a nation-wide universal service based on large-scale power sources and a rate structure largely fixed and standardized geographically and timewise. Going forward, it will be difficult to anticipate a standardized value concerning power supply and utilization given an expected increase in the ratio of renewable energy sources—especially, renewable variable renewable energy (VRE) sources such as photovoltaic and wind power generation whose output varies by weather conditions—and other dispersion-type power sources. Values concerning electricity will be measured not only in terms of energy "quantity" represented by kWh but also in terms of contribution to the total supply capacity of electricity systems represented by kW, supply-demand adjustments in response to short-term changes represented by ΔkW, and other coordination capabilities to support the "quality" of electricity supplied by the entire power systems. Regarding challenges toward realizing such a community-based society, Chapter 2 will discuss technical perspective, and Chapter 4 will elaborate systemic and policy details.

With the position of energy systems, especially electricity systems, in local communities changing, the bulk power system plays an important role for maintaining and improving the entire society's "3E+S." [1] Regionally eccentrically locations and temporal output variation of renewable energy sources make it difficult to complete energy's supply-and-demand process or exchanges of values. The bulk power system, therefore, will have to connect multiple local communities and coordinate the entire systems. Improving the society's overall convenience requires strategic reforms of the bulk power system based on geographical distributions and temporal variation of demand, supply and distribution networks.

Under these circumstances, the local communities' energy systems and the bulk power system will no longer have standardized roles. They will have to be restructured and will coexist. Presently the bulk power systems control the entire electricity systems. In the future, however, an increasing number of local communities will have their own electricity systems with renewable energy and dispersion-type power sources to produce and consume power locally and thereby to improve their resiliency.[2] The bulk power systems will also utilize coordination capabilities provided by the local communities. A society with "3E+S" will be then realized. Developing energy systems unique to the respective local communities necessitates redefinition of the division of roles played by the bulk power systems, including redefinition of systems and policies (social systems) with the said energy systems as implementation means. In relation to initiatives toward reforming the bulk power systems, Chapters 3 and 4 will describe, respectively, technical aspects and systemic/policy aspects.

Also, the future energy systems require establishment of technologies for a new collaboration mechanism to integrate diversified resources. Factors requiring cooperation and coordination will increase, which to include distributed energy resources, linkage between the bulk power systems and the local communities, and coordination with human behaviors. Presently, VPP,[3] resource aggregation,[4] and various other initiatives are in progress that utilize diversified resources. Going forward, it is obvious that factors requiring mutual coordination will further increase in an exponential fashion. It is a significant challenge to control various

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[1] 3E+S: A basic concept of energy policies, comprising energy security, economic efficiency, environment and safety

[2] Resiliency: Ability to recover from disasters, accidents and other contingencies, a value necessary for business continuity planning (BCP)

[3] VPP (Virtual Power Plant): A concept of linking distributed energy generation, storage, and consumption control and other resources through ICT to control them as a virtually integrated large-scale power plant.

[4] Resource aggregation: An approach for integrated control of distributed energy resources through ICT, as in the case of VPP

distributed resources with extremely numerous uncertainties in an integrated manner, unlike controlling the conventional bulk power system based on large-scale power sources, which to entail development of advanced technologies including a combination of autonomous decentralized control and centralized control. From a systemic perspective, it is necessary to realize data sharing for the entire energy systems, promote fusion of real and cyber spaces, and continue to discuss with various stakeholders. It is important for the stakeholders to discuss on an equal basis. We believe that the national government should lead data and tool sharing to facilitate the development of a relevant environment. For example, although renewable energy sources mostly incur zero fuel costs, measures are needed for ensuring quality and stability of electricity systems with renewable energy introduced in a large quantity. Cost minimization for the society as a whole is important. At the same time, obtaining and forming a social agreement requires development of visualizing tools that facilitate common understandings, which to entail data sharing. Regarding initiatives for linking the local communities with the bulk power systems, Chapters 2 and 3 will describe details from a technical perspective, and Chapter 4 will discuss them from a systemic and policy perspective.

Furthermore, Japan has maintained high reliability of its power supply systems and have superb technologies and personnel to support them. We will leverage these strengths in pursuing realization of the vision for energy systems. Chapter 5 will discuss utilization of human resources in more detail.

1.2 Phased approaches from medium- and long-term perspectives

Realizing the vision described in the preceding section 1.1 necessitates discussions from diverse perspectives. In the world with increasing uncertainties, strategically implementing various initiatives should entail formulation of medium- and long-term visions toward 2030 and 2050 and discussions of systems and policies toward the realization of them based on multiple scenarios. Also, a range of technical options should be prepared.

In considering technical options, introduction of renewable energy, which to be one of the major power sources, is a key driver. Especially, given the significant impact of VRE on electricity power systems operation, response measures need to be prepared in a phased manner according to the increase in the ratio of VRE introduced. International Energy Agency (IEA), for example, has proposed steps for introduction of various initiatives according to the percentages of power generated with VRE in annual power generation, also indicating various issues expected to occur in different phases in terms of operational stability and economic efficiency of electricity systems. As response measures for such issues, IEA points out the necessity for flexibility, including regulation or reserve for supply-demand balance, across all areas—power generation, transmission, distribution and consumption (Fig.2). Gaining flexibility not only for conventional large-scale power sources but for numerous distributed energy sources, storage and consumption necessitates new initiatives including strategically assigning grid codes[5] to such distributed resources.

Preparations based on multiple scenarios are also needed for energy storage and stockpile technology development. Matching energy demand with power supply from various energy sources including VRE under the restrictions on carbon emissions necessitates phased development of large-quantity and long-term energy storage capacity. In addition to power storage, storage and stockpiles of new secondary energy sources will be needed at a level equivalent to the conventional oil storage and stockpile level. Regarding these secondary energy sources, it is imperative to anticipate production, storage and timely utilization of them and to plan and introduce production and storage facilities, transportation infrastructures and utilization technologies in time for actual utilization which to become necessary.

Technological development imperative for medium- and long-term scenarios could not be realized solely market forces and necessitates continuous investment from a national perspective. Chapter 4 will discuss in detail a needed framework for implementation from systemic and policy perspectives.

5 Grid codes: Operation requirements for an electricity system (specifically, in this case, requirements for connection between distributed resources and power grids)

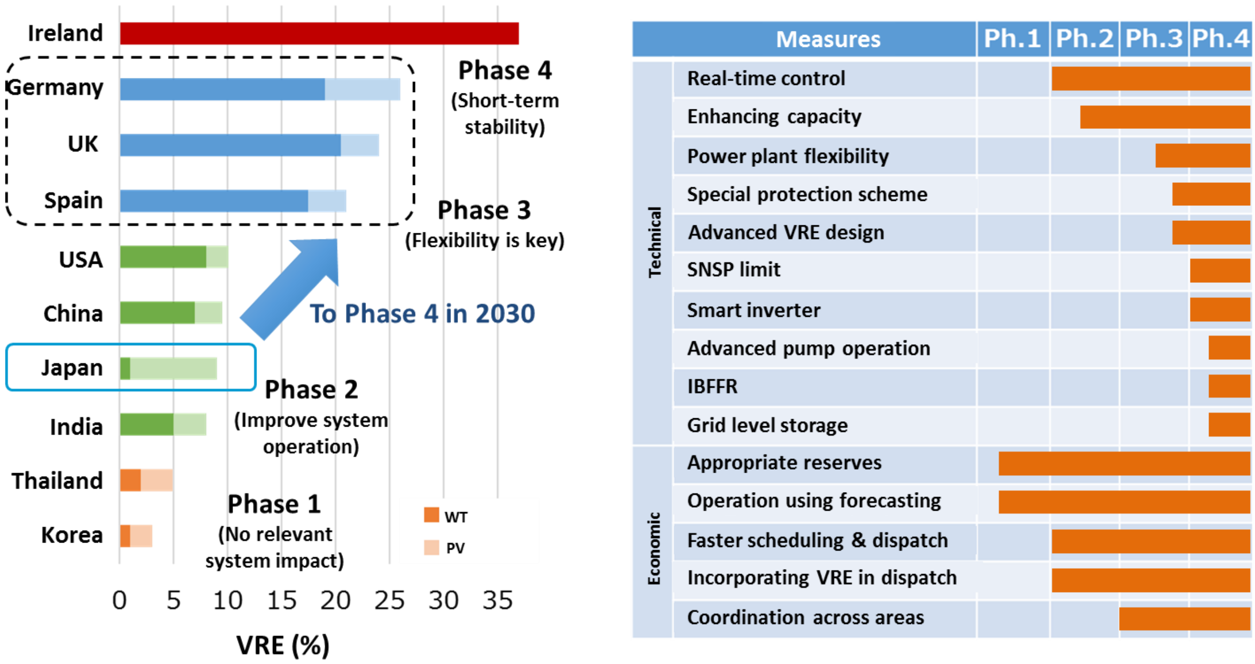


Fig. 2: Quantity of VRE introduced; and initiatives for power system operations

(Prepared based on a report of International Energy Agency (IEA)[6])

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

Chapter 2: New directions to be pursued by local communities

2.1 Local community reforms

As described in Section 1.1, individuals will play the main roles in daily living in Society 5.0, and energy systems unique to each local community will be developed. Energy systems need to be restructured to be suitable for local communities given that not only electricity, gas and water but ICT, automobiles, logistics and other infrastructures will support their daily living in a cooperative and collaborated manner. Values concerning energy used by individuals will be diversified into various kinds--environmental friendliness, including CO_2 reduction and local resources preservation, and convenience and comfort in daily living. Along with the shift from energy consumption to service utilization, energy distribution with service quality will be realized that meets the level required by the respective regions.

Furthermore, as the ratio of VRE and other dispersion-type power sources increases, values concerning electricity will be measured not only in terms of energy quantity represented by kWh but also in terms of contribution to the total supply capacity of electricity systems represented by kW, supply-demand adjustments in response to short-term changes represented by ΔkW, and other coordination capabilities to support the quality of electricity supplied by the entire power systems. In local communities with a shift occurring from energy consumption to service utilization, these new values, too, must be incorporated into distribution and trading infrastructures and systems.

An example of energy value development unique to a local community would be, in the case of an area with suitable locations for renewable energy facilities, utilization of renewable energy and other local resources for fostering local industries in addition to implementation of measures for stable electricity systems. As power generation unit cost declines and approaches grid parity,[7] excess electricity with its marginal cost close to zero per kWh will be proactively utilized. A society creating industries with new local energy usage will be pursued. Part of the initiatives being pursued is to realize interactive distribution of local energy with proactive supply-demand approaches by reviewing Electricity Business Act and other legal systems and rules that have assumed

[7] Grid parity: A situation where PV and other renewable energy-based power generation cost becomes equal to or below exiting commercial electricity systems' electricity cost

unilateral power supply from the bulk power systems to consuming areas. [8]

Regional hub cities should strategically strengthen their energy resiliency. Improving the city's international competitiveness necessitates development of an environment suitable for operation bases of global companies requiring business continuity planning (BCP). Conventionally, in terms of quality of electricity, various legal systems and rules have been established concerning power transmission operators' responsibility for stable power supply and power retail operators' obligation for ensuring supply capability, assuming versatile and standardized service provision. For the purpose of realizing new services relating to resiliency and other values, it is desirable to review these legal systems and rules and proceed with adequate deregulations to enable local communities' energy operators to implement necessary initiatives.

Realizing these reforms necessitate technological innovation and systemic improvement that enable local communities to create, distribute and trade unique values (Fig. 3). To revitalizing local communities' energy supply business, proactive deregulation of legal systems and rules should be sought concerning connection with commercial grid, installation of privately-owned powerline, and wheeling and connection charges. Energy-saving and low-carbon behaviors in household, business operation, industry and transportation sectors are prerequisites. Electrification and motorization will be accelerated in various areas and applications including provision of heating and cooling with heat pumps, electrically-driven automobiles (electric vehicles (EVs) and fuel cell vehicles utilizing hydrogen), and enhanced heat utilization in the industrial sector. New power networks will be developed including rapid charging facilities. As utilization of power electronics and secondary energy sources suitable for large-quantity and long-term storage increases, connecting distributed resources with the electricity systems necessitates innovation of specific technologies such as medium- to high-temperature heat pumps and wireless charging as well as of common technologies such as smart inverters.[9] Section 2.2 will describe initiatives relating to these technologies. Furthermore, developing a system for social implementation of these approaches necessitates data sharing among various infrastructures and benchmarking and sharing of evaluation of local communities' energy and environmental performance. Section 2.4 will describe initiatives

8 The 4th meeting of Subcommittee for Introduction of Renewable Energy in Large Quantity and Next Generation Electricity Network, Advisory Committee for Natural Resources and Energy, Ministry of Economy, Trade and Industry: Material No. 4 (March 22, 2018)

9 Smart inverter: An autonomously or remote-controlled power conversion system providing a range of system services according to conditions of the electricity system. A smart inverter is used for PV, power storage, heat pumps etc. Used interchangeably with such terms as "smart power conditioning system (PCS)."

relating to these approaches.

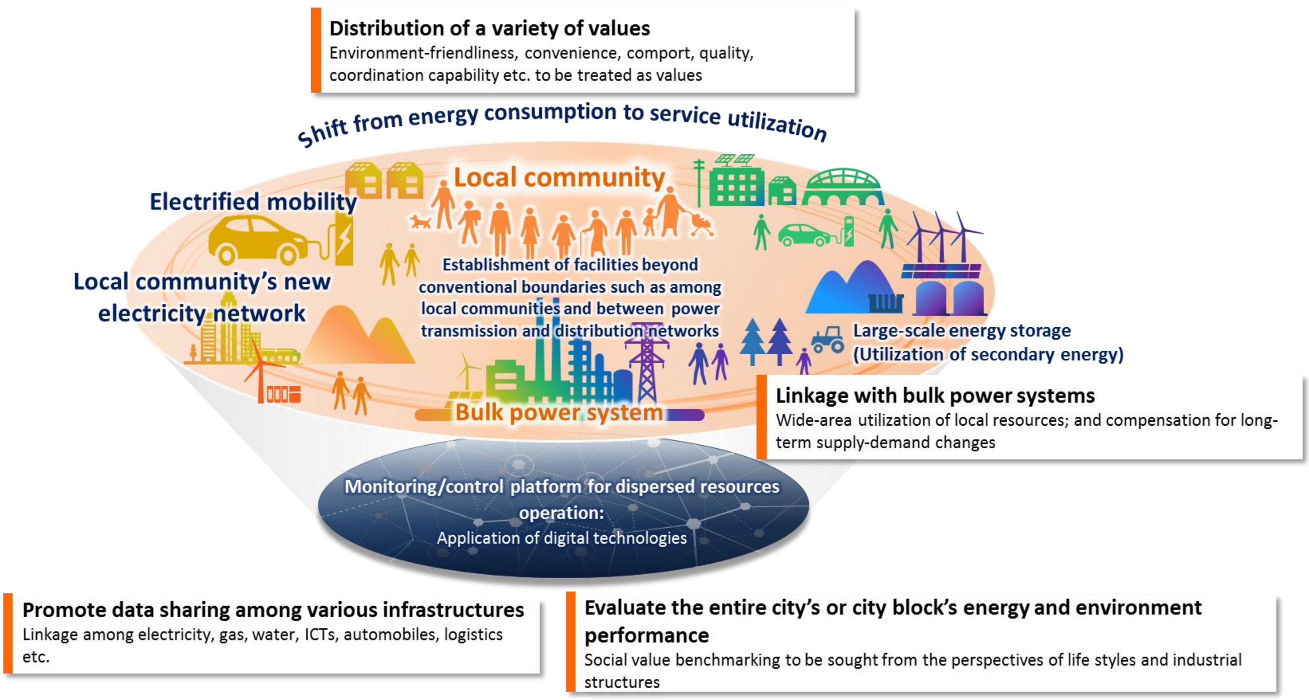


Fig. 3: Changes in local communities' energy systems

2.2 Technological initiatives toward distribution of diverse energy values

Variable output of VRE necessitates provision of coordination capabilities at different times of the day. In addition to conventional thermal power, hydropower, pumped-storage power generation and other large-sized power sources, VRE and other distributed power sources increasing on the side of consumers, demand for EV charging and heat-pump water heating, and batteries and other distributed storage facilities are expected to make contributions. With their overwhelmingly larger number compared to conventional resources, the new distributed resources will have coordination capabilities through dynamic retail prices linked to VRE output fluctuation and autonomous demand management based on such prices. Retail price information and demand management control signals are calculated and distributed as part of the overall electricity system operation planning based on market trading results and reflected to the planning on a real time basis (Fig. 4). The system is not only centrally operated but partly by an aggregator who manages multiple demand sources. Realizing this new supply-demand management necessitates not only development of technologies used at facilities but development of systems including distributed resources management infrastructure utilizing digital technologies and electricity system and market operation systems utilizing such infrastructure.

Local communities' distributed resources management contributes to stable and economic electric system operations through supply-demand and voltage coordination at various times of the day. They should not, at the same time, damage comfort associated with thermal environment, mobile services, etc. It will be, therefore, necessary to grasp and analyze household and business operation sectors' demand for services and evaluate the potentiality of a range of energy consumption forms. It is imperative to develop a common evaluation platform for analyzing many demand patterns, analyzing responses to retail prices and remote control based on them, and analyzing and evaluating the aggregator's operation plans for the purpose of disseminating various technologies under restrictions (e.g. grid code in the case of electricity), reviewing facility development and establishing new operation technologies.

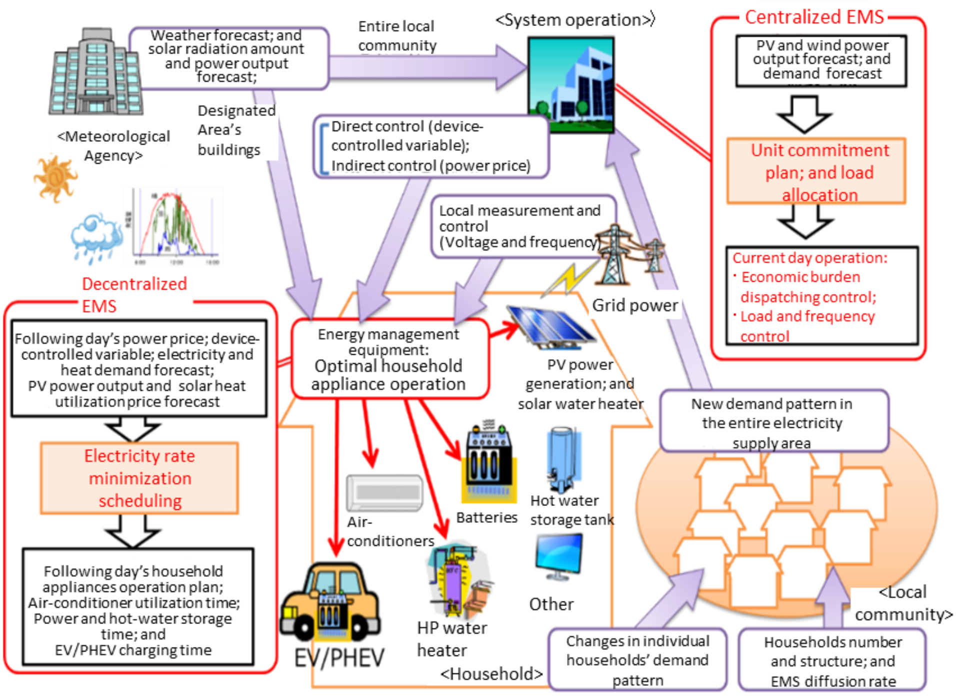


Fig. 4: Utilization of autonomous management and remote control of a local community's distributed resources for provision of services

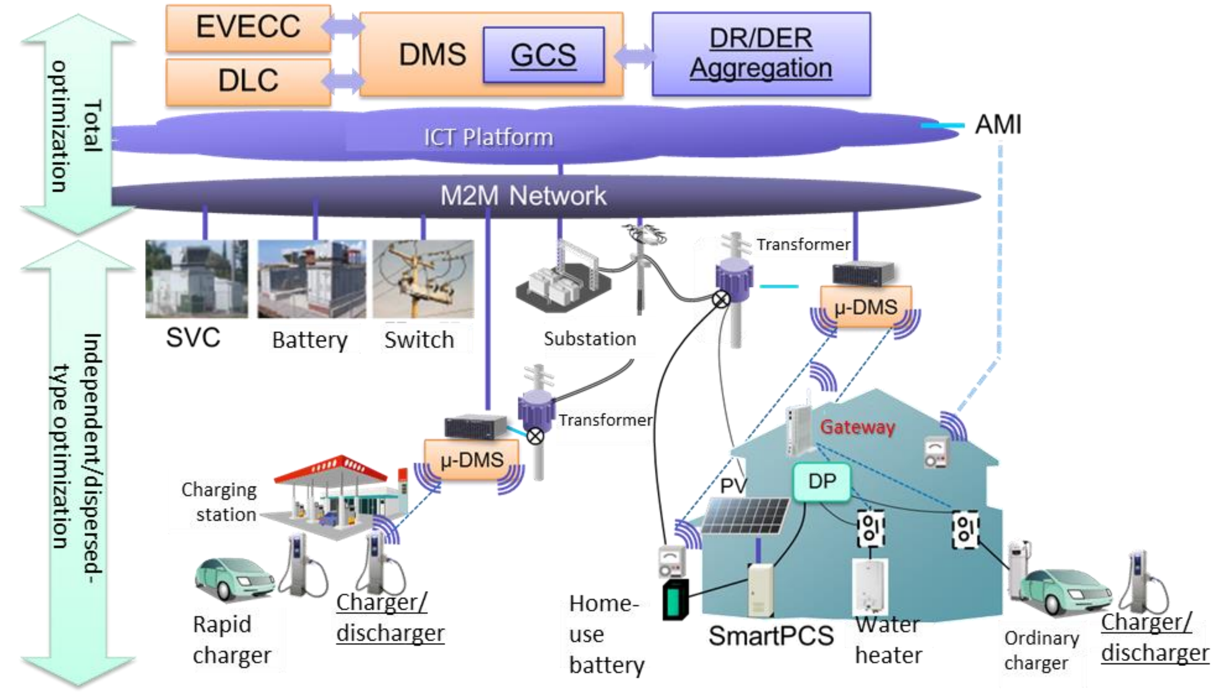
(Source: Paper presented at annual conference of power and energy society, IEEJ by Ogimoto Laboratory, the University of Tokyo[10])

[10] Ogimoto, Iwabune, Kataoka, Ikegami, and Yagita. "Collaborative Model for Centralized and De-centralized Energy Management Toward Improving Electricity Supply-Demand Coordination Capability," annual conference of power and energy society, IEEJ, I-16 (2011).

The Japan - U.S. Collaborative Smart Grid Demonstration Project in Maui Island of Hawaii State, led by New Energy and Industrial Technology Development Organization (NEDO), verified technologies utilizing a range of distributed resources that can respond to drastic supply-demand imbalance caused by various factors such as the duck curve problem[11] in photovoltaic power generation and unexpected disconnection in wind power generation due to a strong wind (Fig. 5). The project confirmed a value-creating flexibility that had been buried in local communities. On the other hand, this kind of social experiment has its own limit; these technologies are still at a demonstration stage.

Going forward, as distributed resources to be controlled will increase in an exponential manner, it is necessary to establish a new collaboration mechanism for integrating these distributed resources. It is imperative to accelerate the realization of a new collaboration mechanism by substantially expanding the scale and number of demonstration projects to promote social implementation based on industry-academia-government cooperation for forming a social agreement concerning and establishing a system for utilization of a range of distributed resources.

[11] Duck curve problem: Daytime solar power output decreases electric demand in locations where a substantial amount of photovoltaic power generation has been installed. Total power demand generally increases after sunset, when solar power is no longer available. As a result, the demand curve for power less solar power rises sharply after sunset.



EVECC: EV Energy Control Center
DMS: Distribution Management System
DLC: Direct Load Control
DR: Demand Response
AMI: Advanced Metering Infrastructure
M2M: Machine to Machine
SVC: Static Var Compensator
DP: Distribution Panel
PV: Photovoltaic
PCS: Power Conditioning System
GCS: Grid Control System
DER: Distributed Energy Resource

Fig. 5: Example of utilization of distributed resources used in the demonstration project in Maui Island (NEDO: The Japan - U.S. Collaborative Smart Grid Demonstration Project in Maui Island of Hawaii State)

2.3 Promotion of data sharing among various infrastructures

Developing a public system for sharing information of various infrastructures—including not only electricity, gas, and water but ICT, automobiles and logistics—would facilitate creation of new services and businesses. The conventional mechanism where different infrastructures are operated and maintained by different operators has worked during the economic growth period. Going forward, however, as alternation and fusion of infrastructures progresses along with the trend of diversification, digitalization, electrification and motorization, it is necessary to revise the vertically-divided conventional management system by utilizing information. Gathering and utilizing information necessitates not only deregulations concerning information sharing but a development of public information sharing mechanism led by the national government, thereby preventing excessive monopolization of information, encouraging adequate competition in industry and academic areas, and creating innovative industries and employment that contributes to the realization of Society 5.0.

An example of an initiative for data distribution is a City Data Exchange (CDE) project that the City of Copenhagen is working on (Fig. 6). The City of Copenhagen aims to be the world's first carbon-neutral city by 2015. The City plans to reduce its CO_2 emission from today's approx. 2 million tons per year to 1.2 million tons by 2025. Toward achieving this target, the Copenhagen Cleantech Cluster (currently CLEAN) project, which to promote the introduction of innovative environment and energy-related technologies in Denmark, in 2014 indicated its environment-friendly infrastructure vision based on collection of various data relating to public and private sectors and bigdata analyses.

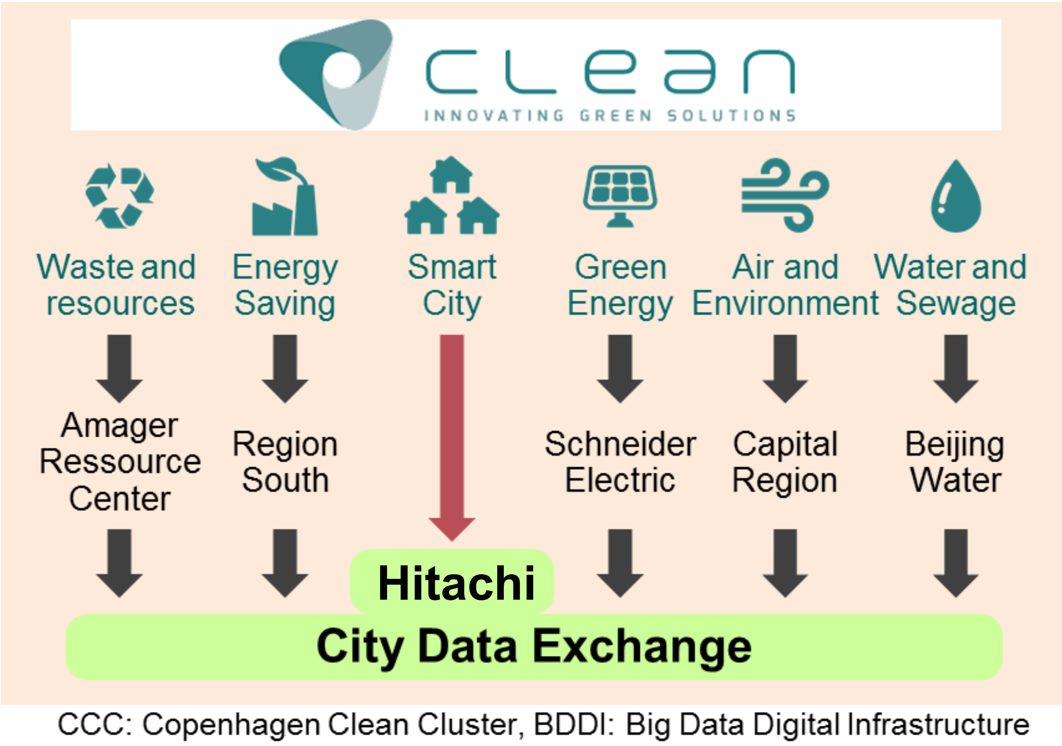


Fig. 6: City Data Exchange (CDE) project

2.4 Evaluation of total energy and environmental performance of cities and city blocks

Redevelopment of a city or a city block should be strategic redevelopment of infrastructure based on benchmarking and sharing of energy and environment performance of the city or the city block and adequate incentives, focusing on social values that the local community pursues from the perspectives of people's daily living and industrial structures beyond the scope of specific equipment or buildings. Available benchmarks for environment assessment of buildings in infrastructure redevelopment include Japan's CASBEE,[12] the U.S.' LEED,[13] and Europe's BREEAM.[14] Many of them, however, evaluates individual buildings. CASBEE is the only system that seeks to provide an environment benchmark for areas. Yet, CASBEE's environment evaluation of an area does not get reflected to the area's property values; it does not provide a benchmark that contributes to the community by increasing values. Moreover, CASBEE is used basically only in Japan. Its further enhancement and global roll-out should be pursued.

Also, sharing data relating to cities' and/or city blocks' energy and environment performance would encourage creation of business opportunities including energy interchange. Currently, such data management programs as Building Information Modeling (BIM) and Construction Information Modeling (CIM)[15] are being disseminated especially in Europe and the U.S., used from the commencement of construction of buildings and local infrastructures including water and gas facilities to the time of maintenances. BIM and CIM prepare 3D CAD data from the time of commencement of construction and mange digitalized records of maintenances and repairs and, therefore, expected to be utilized systematically for urban development policies. On the other hand, given that their purpose is mainly the maintenances of static buildings and infrastructure facilities, they do not readily reflect dynamic changes in local communities. Utilizing information more dynamically necessitates an integrated analysis of the private sector's BIM and the pubic-sector's CIM and hence development of a system led by the national government.

Periodic disclosures of the energy and environment performance of cities and city blocks would encourage adequate competition among local communities. As described in Section 2.1, creating, distributing and trading local communities' unique values utilizing the above-mentioned benchmarks would bring about changes in social structures and individual life styles in the respective communities.

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[12] CASBEE: Comprehensive Assessment System for Built Environment Efficiency, an environment performance assessment system developed by a committee of Institute for Building Environment and Energy Conservation

[13] LEED: Leadership in Energy & Environmental Design, an environment performance assessment system for buildings and their premises, developed and operated by U.S. Green Building Council

[14] BREEAM: Building Research Establishment Environmental Assessment Method, a building performance system developed by the U.K.'s Building Research Establishment

[15] CIM: Construction Information Modeling, 3D modeling used for information sharing in the area of civil engineering in planning, survey, designing, construction and maintenance/management phases (which is to be distinguished from Common Information Model, another term)

2.5 Linkage with bulk power systems

The above-described initiatives aim to develop a society where local communities' unique energy values are created, distributed and traded. At the same time, they will lead to transfer of energy supply, demand and values across multiple local communities. In this regard, the bulk power systems will provide linkage among multiple local communities. We must also anticipate gaps in values to expand along with the trend toward strengthening of local characteristics.

Also, maintaining the bulk power systems necessitates flexible provision of values from a range of distributed resources available in the local communities. Conventionally, the electricity transmission and distribution sectors have ensured reliability and quality of power supply, and their roles in doing so have been established. Going forward, in developing different local communities' unique energy systems, it is necessary to reconsider values to be provided by the local community to the bulk power system and to redesign the division of roles to be played by the bulk power systems that will be responsible for "3E+S" of the entire society. Chapter 3 will discuss in more detail the linkage between the local communities and the bulk power systems.

Chapter 3: Framework to support changes in bulk power systems

3.1 New roles of the bulk power systems

In the changing energy systems, the bulk power systems assume important roles for improving "3E+S" of the society as a whole. When energy supply, demand and values are transferred among multiple local communities, the bulk power systems provide linkage for them. Furthermore, conventionally, vertically integrated regional power companies ensure not only kWh-based output but also other values such as stable supply and environment friendliness. When the power transmission and distribution are separated, the energy system as a whole will have to ensure these values with quantification and benchmarking. To this end, the energy system as a whole must conduct technological and quantitative analyses and evaluation based on systems and policies to be mentioned in Chapter 4. For example, if energy supply cost from renewable energy sources, including the effect of subsidy, becomes lower than the retail rate, consumers who can afford to make facility investment might develop an independent electricity system and get it disconnected form the commercial grid. Then, an imbalanced situation can be anticipated where the remaining consumers would have to bear the increasing cost of grid maintenance. Local communities' energy systems must evaluate the technologies to be used, systems and policies based on multiple evaluation criteria such as long-term business sustainability taking equality and welfare into consideration, environment values, and energy security, instead of only evaluating the cost effectiveness of the investment based on the present costs.

With the country's large islands lined up from the north to the south, Japan's bulk power systems consist of regional power systems serving a large demand that are linked to each other through AC and DC interconnections. Therefore, Japan faces problems associated with large-quantity introduction of renewable energy sources—such as frequency, voltage and stability—ahead of other countries (Fig. 7). We will promptly solve these issues and globally roll out relevant technologies and knowhow to contribute to the international society.

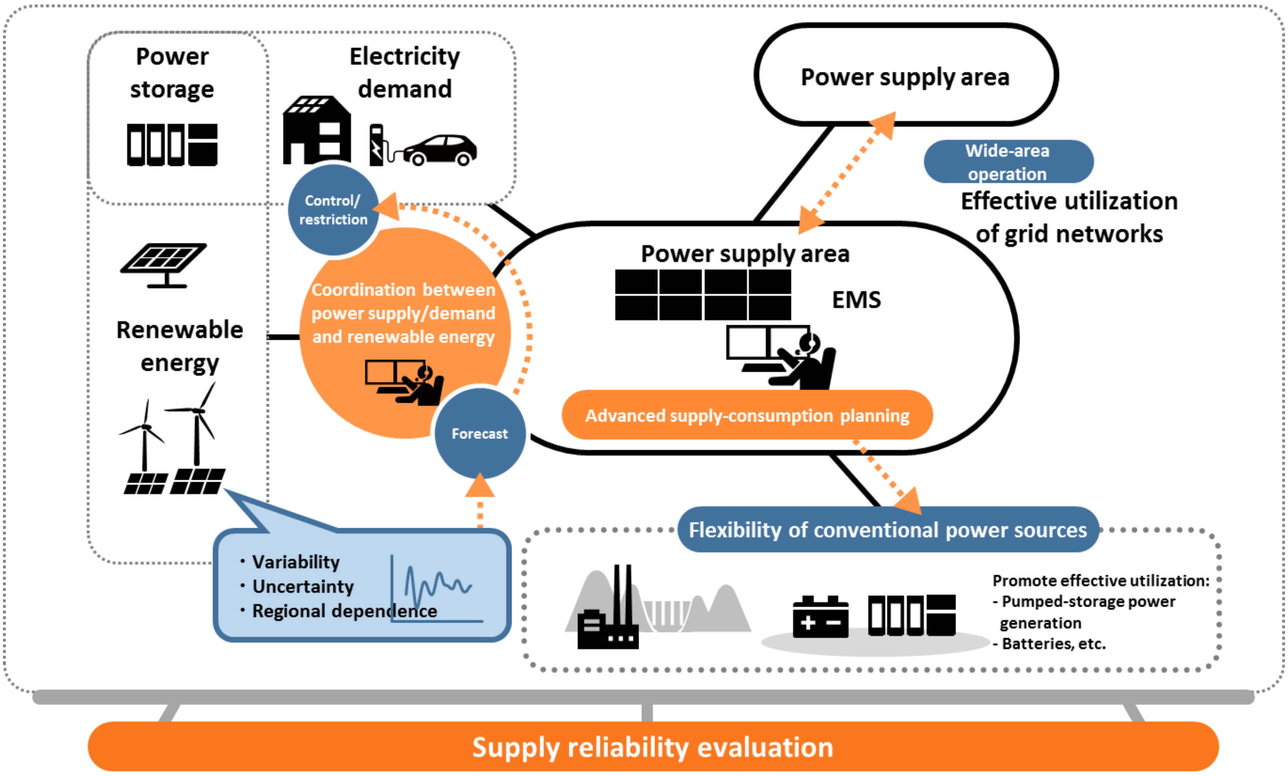


Fig. 7: Illustration of supply and demand of electricity when renewable energy sources are introduced in large quantity

3.2 Evaluation environment for bulk power systems

Having the bulk power systems fill their expected roles necessitates establishment of an analysis and evaluation environment for electricity and other energy systems of the entire society. Realizing desirable bulk power systems entail identification of various future challenges, quantitative measurement of cost effectiveness of facility investment, and implementation and sharing of evaluation of solutions from a range of standpoints.

To this end, industry-academia-government cooperation is needed to develop and share analytical tools and standard data and thereby to develop a platform. 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 not only the bulk power systems and local communities but also various other factors, such as EV connectivity and hydrogen conversion and storage, toward achieving the government targets including the power source configuration in 2030 indicated in the long-term energy supply-demand outlook and reduction of CO_2 by 80% by 2050.

Examples of analytic tools for electricity systems are Supply and Demand Simulation System and Wide-Area Grid Stability Simulator. Electric Supply-Demand Analytical Simulator is being researched and developed jointly by Central Research Institute of Electric Power Industry, TEPCO Power Grid, the University of Tokyo etc. that are commissioned by NEDO. It is a tool for evaluating challenges concerning power supply and demand in various time periods—from the order of seconds relating to renewable energy's volatility, uncertainty and regional dependence to years and sometime in the future. Incorporating thermal power generation's flexibility, electricity storage including pumped-storage power generation and batteries, and inter-regional connections, it helps consider enhancement of power supply-demand planning and reliability criteria for flexibility (Fig. 8). For example, it has considered power supply and demand and direction of technological development assuming the large-quantity introduction of renewable energy sources around 2030 to the anticipated regional electricity systems in eastern Japan.

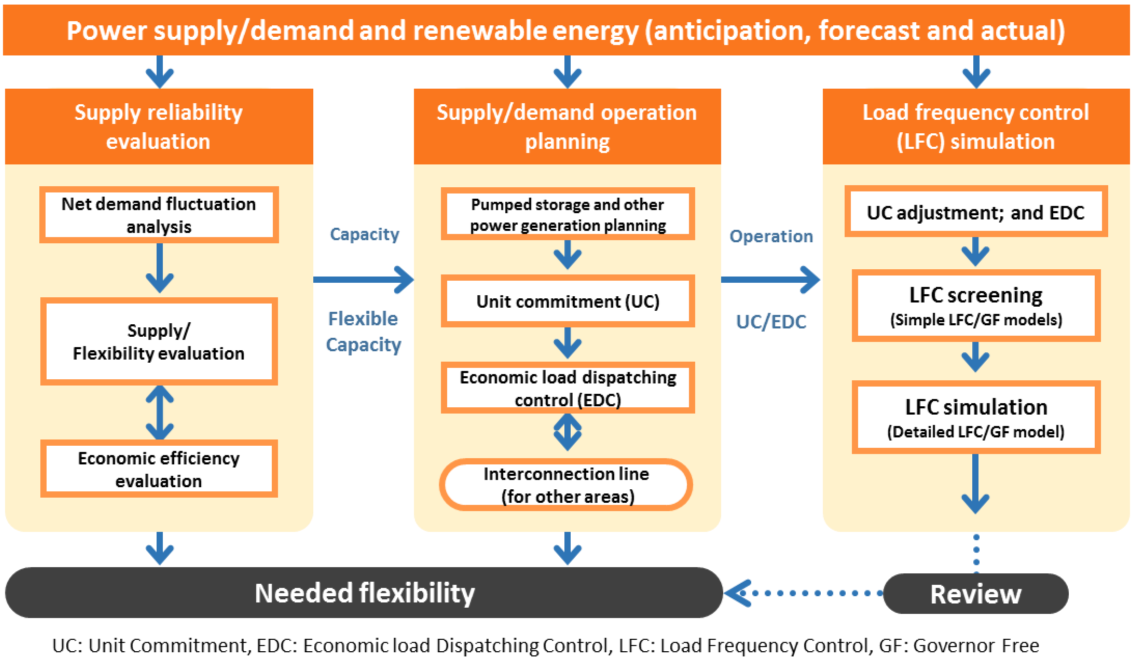
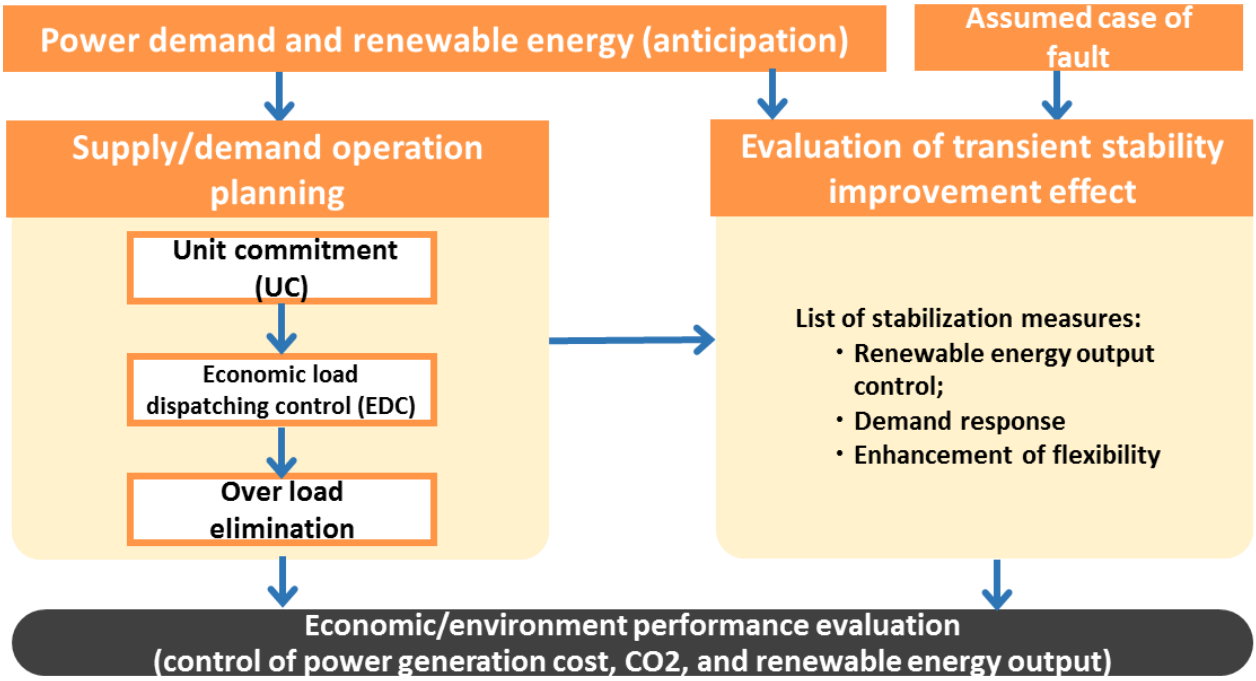


Fig. 8: Outline of the electricity supply-demand analytical simulator

The Wide-Area Stability Simulator is being developed by Hitachi. It is an analytical tool for evaluating various initiatives toward the introduction of renewable energy from technological and benefit perspectives. It helps consider the limit for the introduction of renewable energy and determine required control over output at the time of large-quantity introduction of renewable energy while ensuring supply-demand balance and considering transient stability based on anticipated failures in various regions' systems. It calculates various evaluation indicators such as changes in annual power generation costs and CO_2 emissions. For example, it has started consideration of eastern Japan's grid system using a stability evaluation model (Fig. 9).



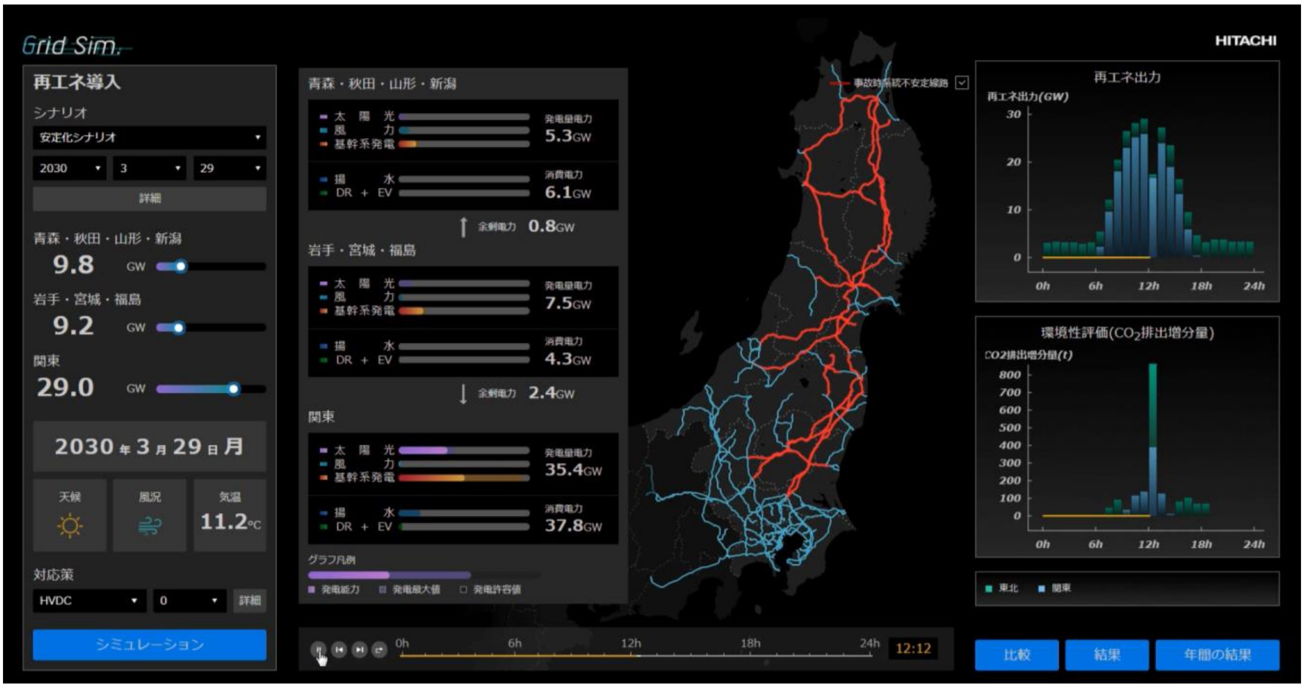


Fig. 9: Wide-Area Stability Simulator

Data sharing is a prerequisite for open discussions by various stakeholders based on these evaluation tools. It is imperative for the national government to lead and accelerate formulation of rules concerning data disclosure, publishing and sharing based on having the importance of data sharing understood by stakeholders in the industrial, academic and government sectors. The standard data must reflect scenarios concerning present and future power output and demand and facility configurations with approximation to reality. Furthermore, in the cases of control parameters specific to power generators and other information that are difficult to disclose due to intellectual property rights, confidentiality of the detailed information should be maintained through encapsulation when they are used f or analyses. For example, the Institute of Electrical Engineers of Japan has disclosed standard system models (EAST 30, WEST 30,[16] etc.) that are anticipated to be used in stability analyses. They serve as a useful reference concerning data item requirements. Outside Japan, U.K.'s National Grid and ENTSO-E publish data concerning systems configurations and tidal current conditions. They serve as a useful reference as it is a form of data sharing.

3.3 Digital linkage among local communities' control systems

Future energy systems need to incorporate and implement new control technologies for digitally connecting the bulk power systems with the local communities and, concurrently, develop market trading systems and systemic designs. For example, new control technologies—such as virtual power plants (VPPs), demand responses and smart inverters for renewable energy—need to be developed. The existing systems' potentials should be effectively utilized to maximize the cost effectiveness of the social system by having local communities' power control perform part of the supply-demand coordination function that is presently performed by thermal power and pumped-storage power generation facilities. To this end, it is important to develop IT infrastructures for linking local communities' enormous facilities, control schemes for maximizing their effects, incentives and other rules. As described in Chapter 2, an approach would be mutual coordination utilizing local communities' coordination capabilities by communicating kW values and ΔkW and other "quality" values of electricity generated from the entire electricity system to the local community directly (in the form of instructions) or indirectly (in the form of incentive). As a reference case, NEDO's demonstration experiment in an island (Niijima, Tokyo), "Mitigation Technologies on Output Fluctuations of Renewable Energy Generations in Power Grid," is explained in the following. This Project considers various challenges and solutions using a model power system in Niijima based on the anticipated ratio of renewable energy sources to be achieved around 2030 in Japan. For example, the Project developed and evaluated a grid system based on forecast output from renewable energy sources, output control, and collaborative operation control with existing power sources and batteries.

[16] EAST 30 and WEST 30: Names of the standard models formulated by IEEJ. The numbers represent the numbers of power generators.

Specifically, operations are implemented with optimized combination of measures for excess electricity, fluctuation mitigation and planned power generation. Also, coordinated operations of multiple dispersion-type control system were tested, anticipating resource aggregation and balancing groups that are expected to accompany future electricity systems reform (Fig. 10).

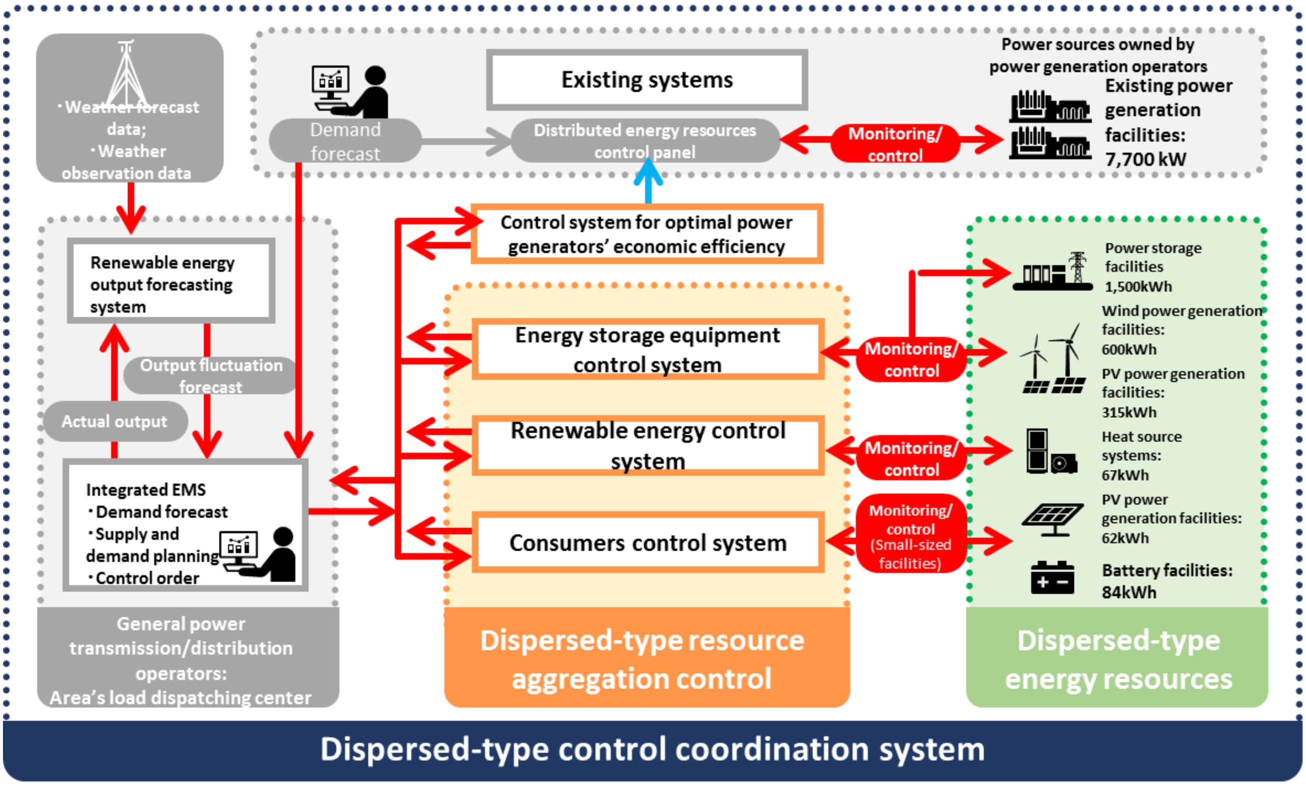


Fig. 10: Demonstration of a model electricity system based on the anticipated energy mix for 2030

(Prepared based on TEPCO's website[17] (Apr. 13, 2017))

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

3.4 Evolution to a cyber-physical evaluation platform

Going forward, it is necessary to further evolve the evaluation platform for the bulk power systems that were mentioned in Sections 3.2 and 3.3. In the past, the bulk power systems have increasingly contributed values to the society through total optimization based on linkage with neighboring bulk power systems in wide-area operations. In the future, they will deepen their linkage with power distributors and consumers and have a complicated cross-industry linkage with mobility systems and other non-energy industries (Fig. 11). Along with this trend, an evaluation environment will be developed and shared that will link individual simulation tools, incorporate real data and develop into a cyber-physical system (CPS) enabling operations in cyber spaces. It will further develop into an environment that will be able to evaluate energy systems supporting Society 5.0 and encourage discussions among many stakeholders about a new world.

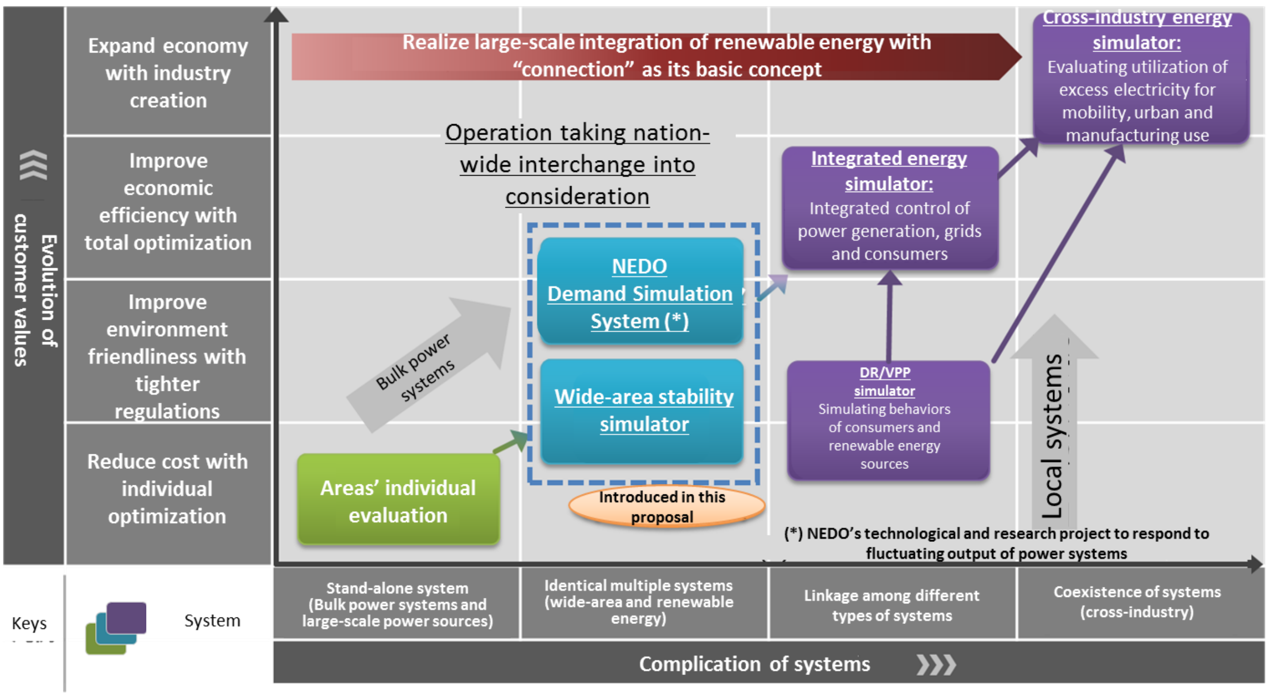


Fig. 11: Evolution of energy systems evaluation environment

Chapter 4: Systems and policies for addressing challenges and implementing reforms

Global economic and social changes and technological innovations cause uncertainties to increase in the energy sector. Given inevitable increases in the introduction of renewable energy, digitalization and diversification, a significant shift is occurring in the energy supply-demand structure from a supply-side-oriented structure to a total optimization structure incorporating the demand-side. These discrete changes in the energy systems necessitate changes in Japan's energy policies which to address challenges.

4.1 Multiple system and policy options

Political, economic and technological uncertainties are increasing in the whole energy sector due to changes in the world situations concerning energy resources, diversification of market participants on a global level and various potential technological innovations including EVs, batteries and hydrogen. In this age of uncertainty, a scenario analysis framework based on evidence-based policy making (EBPM) [18] should be introduced, which to enable flexible decision-making.

As opposed to prediction of a single outcome in the future, scenario analysis considers alternative multiple outcomes in the future to design energy systems and relevant approaches under each scenario. With highly uncertain economic environment and geopolitical risks as variables, it analyzes the impacts of such variables on the energy sector and helps prepare relevant approaches. In recent years, many governments and companies have introduced scenario analysis to prepare themselves for uncertainties.

In Japan, based on variables that have significant impacts on Japanese society, multiple scenarios concerning transitional approaches toward 2030 and then 2050 will be discussed toward establishing a policy-making process that takes into consideration possible environment surrounding the energy sector and risks and incorporates relevant response measures.

[18] Evidence Based Policy Making (EBPM): In this context, EBPM refers to a policy-making process where hypotheses concerning policy options are developed and verified based on statistical, simulated, or other objective data (evidence) and where policies are formulated through open discussions among multiple stakeholders.

An example is as follows. Multiple scenarios are prepared with future geographical risks in Middle East and East Asia as a variable. Then an optimal energy supply-demand situation for each scenario—including renewable energy, nuclear power and fossil fuel-based energy sources—is considered. Furthermore, a policy-making process will be established within the EBPM framework that considers various policy options concerning energy networks including cyber security measures and international grid connectivity as well as related policies such as carbon pricing, taxation, international financing and resource policies.

Incorporating EBPM as a process of consultation with stakeholders, the scenario analysis will quantitatively evaluate policy options' validity, feasibility and effectiveness to consider multiple approaches toward achieving the target of reducing CO_2 emissions by 80% by 2050. Based on this process, national strategies that integrate energy, environment and economic strategies from a global perspective will be formulated, which to lead to long-term strengthening of the energy industry. Also, the strategies will be regularly updated according to the latest social situations to ensure policy consistency.

Preceding scenario analyses have been conducted by U.K., Germany, and other countries, where multiple long-term scenarios were formulated toward achieving the government's targets including the reduction of greenhouse effect gas emissions. U.K. has formulated four long-term scenarios toward achieving the 2 degrees Celsius target [19] by 2050 based on economic growth and social/policy orientation toward environment friendliness (Fig. 12).

Each scenario shows changes in power demand and CO_2 emissions based on power source structures and levels of diffusion of EVs and electricity storage technologies and other variables. They are revised every year based on consultation with stakeholders. They thereby help clarify approaches toward achieving the targets and technological and social conditions and lead to consideration of measures concerning the electricity systems and promotion of innovations.

[19] The global long-term target of Paris Agreement to keep the global temperature rise below 2 degrees Celsius above pre-industrial levels

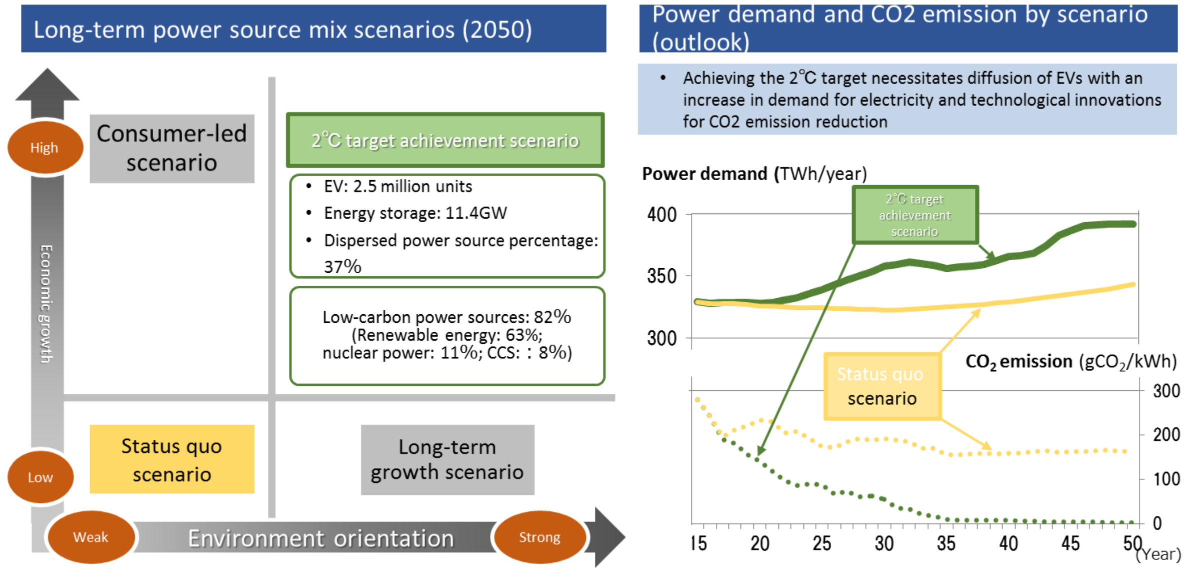


Fig. 12: U.K.'s energy scenarios

4.2 Performance-driven policies

Introduction of renewable energy sources, digitalization and diversification will make progress toward the achievement of government targets including the power source structure[20] for 2030 as anticipated in the long-term energy supply-demand outlook and reduction of CO_2 emissions by 80% by 2050. Redeveloping the energy systems as described in Chapters 1 to 3 necessitates continuous investments and innovations. Given, however, significant uncertainties involved in the medium- to long-term scenarios, strategic investment needs to be made from national and global perspectives, leveraging social efficiency enhanced by the market mechanism.

These investments and innovations should contribute not only to realization of economic benefits but to energy security and sustainable development goals (SDGs[21]). These perspectives should be incorporated into concrete target setting and outcome evaluation.

Target setting should involve and reflect discussions among multiple stakeholders concerning values, that Japan's energy industry should realize from the perspectives of economic efficiency, environment, energy security and safety or "3E+S." Also, continuous improvement should be sought based on quantitatively

[20] Target of the long-term energy supply-demand outlook for 2030: 22-24% renewable energy

[21] SDGs：Sustainable Development Goals

evaluating the degrees of achievement of targets with open analytical tools and standard benchmarks by implementing PDCA with stakeholders involved. A system should be introduced that smoothly leads the society toward achieving the targets while indicating a common direction. Furthermore, in terms of energy system investment, cost allocation rules[22] should be established together with approaches for cost-effectiveness analysis that take CO_2 emission reduction and energy security into consideration. We call such policies, which to realize values based on evaluation of outcomes, “performance-driven policies.”

The performance-driven policies set targets from long-term perspectives and require quantitative evaluations. They will realize consumers’ benefits from “3E+S” perspectives and, at the same time, help improve business predictability for energy companies. In the environment with increasing uncertainties, incorporating PDCA based on outcome evaluation into the policy-making process, in addition to predictability ensured through capacity and other market mechanisms, encourages investments and innovations and thereby promote restructuring of energy systems.

An example of an overseas preceding initiative would be U.K.’ network price control policy, RIIO.[23] As Figure 13 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. Furthermore, RIIO provides incentives[24] 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.

[22] Fair and transparent rules on cost allocation are needed concerning expansion of grid capacity in response to the introduction of renewable energy sources with uneven geographical locations.

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

[24] 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.

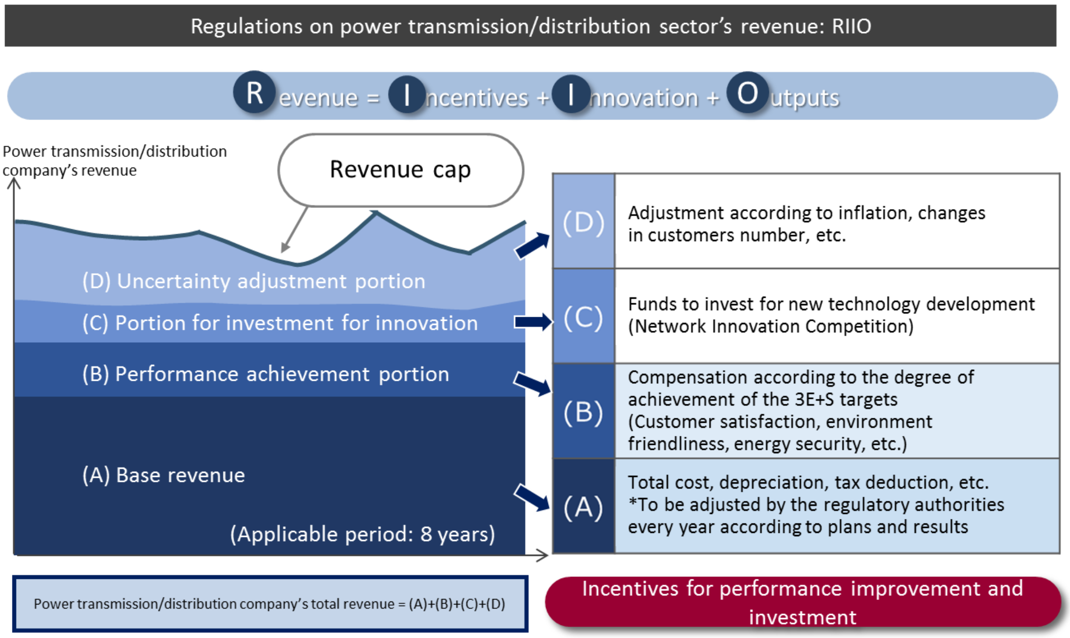


Fig. 13: U.K.' RIIO

4.3 Redevelopment and global roll-out of energy systems

In Society 5.0, individuals will play the central roles in daily living, and energy systems will be developed that reflect local communities' characteristics. New values and services will be thereby provided. Also, the local communities and the bulk power systems will be restructured while coexisting. The entire society's 3E+S will improve. Furthermore, advanced systems established in Japan will be rolled out globally, contributing to the international society. To this end, utilizing scenario analysis, the government will show a future vision of energy systems from medium- to long-term perspectives. It will also formulate rules necessary for the future system as described in Chapter 1 while referring to the global standards.

For example, the government should develop new value assessment and trading systems[25] including revising laws and regulations to enable interactive energy trading between a local community's system and a bulk power system. Also, regarding power transmission and distribution operators' responsibility for stable supply, transferring authorities and responsibilities to new operators would help realize creation, distribution and trading of regions' various values as described in Chapter 2. Furthermore, the government should aim to create new services and to develop new technologies by developing an open system for sharing data concerning various

[25] For example, market and regulatory frameworks concerning various values such as ΔkW value, kW value, environmental value by power source, and value by time of the day

social infrastructures and establishing relevant IT infrastructures. Also, we will seek to realize analytical tools mentioned in Chapter 3.

Concurrently, the government should review procurement guidelines and procedures and consider standardization and de facto standard strategies including developing utilities' grid code.[26] Furthermore, based on developing international finance and CO_2 credit frameworks and the above-described market rules in an integrated manner, we will globally roll out the energy systems[27] developed in Japan, thereby contributing to the international society.

The energy industry will develop an open, collaborative and creative relations with other industries to create a new value creation network[28] based on extensive data linkage. It will thereby promote investments and innovations and enhance its global competitiveness. In developing the value creation network, it will develop data linkage within and outside the industry in an agile manner without formulating or installing standardized technical specifications. To this end, each system's technical specifications will be widely disclosed to ensure transparency. Furthermore, experience and knowledge gained from value creation network development will be shared and incorporated into the systems to accelerate systems development.[29] These initiatives will help realize cross-industrial fusion in both cyber and physical spaces, thereby helping create a new industry, enhance the industry's global competitiveness and roll-out advanced systems globally. Also, knowledge gained from overseas markets will be utilized for improving domestic systems. Continuous improvement is thus sought. The academia will share directions with the government and companies toward solving social issues including energy. Its research results will be leverage for creating new values. It will also foster individuals with cross-sectoral perspectives.

With respect to the energy sector's future technologies with significant certainties, the industry, the academia and the government should cooperate in pursuing diverse potentials. Also, they should encourage competition

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[26] For example, grid code concerning distributed resources is adopted prior to the establishment of facilities to improve grid controllability.

[27] Referring to not only energy network technology but the overall energy system including resources on the consumer side such as renewable energy, clean coal fuel source, and heat pumps

[28] Value creation network: A total network including the supply chain for energy facilities and the value chain for energy conversion and transportation

[29] A direction consistent with the concept of Society 5.0 proposed by the Council for Science, Technology and Innovation, Cabinet Office

among technologies to select and foster technologies that will be truly necessary in the future global market. To this end, they should share and utilize data to develop scenario analysis frameworks, performance-driven policies (Chapter 4), performance evaluation benchmarks for cities and city blocks (Chapter 2) and analytical simulators (Chapter 3) as shared platforms for discussions among multiple stakeholders including the industry, the academia and the government and for social decision-making.

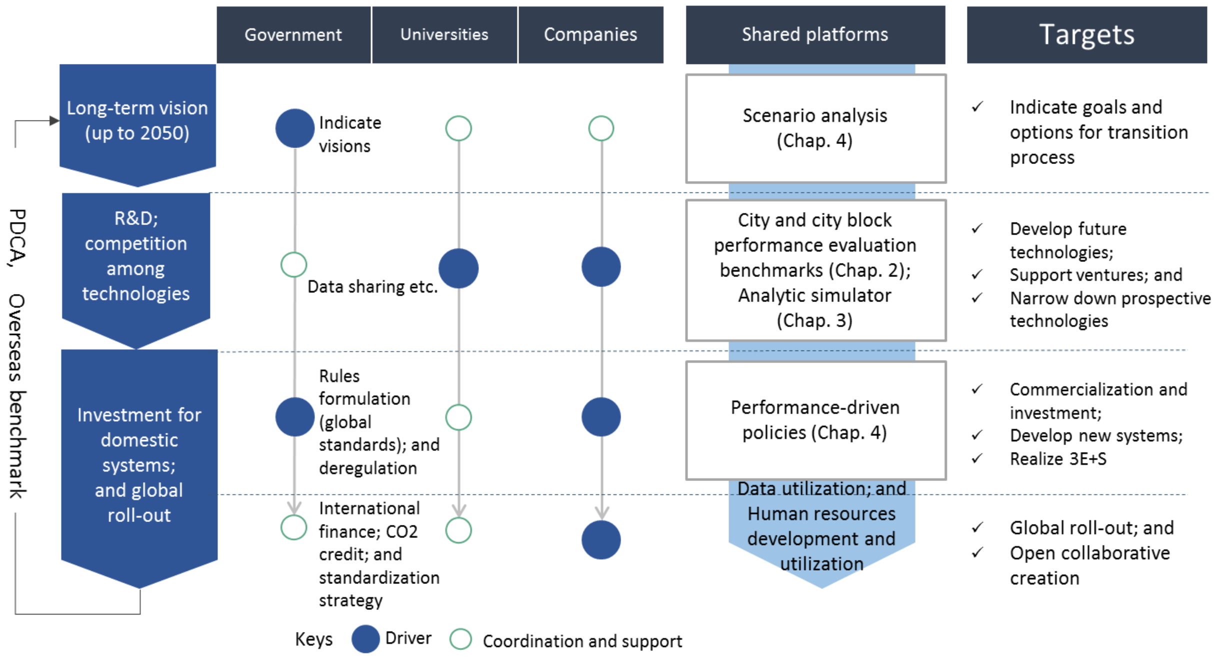

Fig. 14: Industry-academia-government cooperation and shared platforms

Japan must respond with its own strategies to significant changes occurring in the energy value chain—including European, Chinese and other foreign energy companies' globalization, American IT companies' entering into energy businesses, and ESG investment[30] causing changes in destination of risk money.

4.4 Cyber security

Society 5.0 anticipates interconnections between hardware and IT and other information devices beyond conventional industrial segments. It also requires infrastructure control based on data distribution including information disclosure and sharing. In these circumstances, for ensuring soundness of infrastructure systems and strengthening energy security, an important factor in "3E+S," cyber security is imperative.

[30] ESG investment: Investment into companies emphasizing environment, social and governance values.

Maintenance and operation of energy systems and other key infrastructures is significantly dependent on information systems. In a society where everything is connected, cyber security directly relates to overall security. Infrastructure systems, therefore, must achieve a high level of security from the perspective of overall security. In addition to measures to be taken by private-sector companies, the national government should formulate relevant policies, taking the following points into consideration.

In response to ever expanding and increasingly sophisticated security threats, it is necessary to strengthen security measures for the entire value creation network including the energy networks and other energy distribution systems. While making systems specifications open for mutual connectivity among systems, it is necessary to adopt the concept of "security by design" that require the whole systems, including external connectivity, to be designed from the ground up to be secure.

Mission assurance[31] needs to be implemented. Also, organizational governance must be established including clarification of procurement security policy, confirmation of evidence, development of organizational units handling operational security.

The U.S. Department of Energy sets mitigation of risks on supply chains as a core strategic goal of cyber security and prioritizes the examination of vulnerability based on public and private-sector cooperation. Department of Defense has added supply chain risk management to the requirements concerning energy equipment for the military facilities. Part of the aims of these initiatives is to incorporate private-sector specifications to the government's procurement standards to make a de facto standard a de jure standard[32] and thereby to strengthen the industry. In the future, the energy industry's security control capability concerning the value creation network will be a prerequisite for conducting business. Measures from a national perspective, including standardization strategy, will be required.

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[31] Mission assurance: Fulfillment of systems-related responsibilities and completion of critical infrastructure-related functions and services by the person in charge of operations including risk analysis and reporting to the management for overall decisions.

[32] To adopt a de facto standard as a de jure standard

Chapter 5: Human resources development to support energy systems

5.1 New personnel development

Developing energy systems to support Society 5.0 and concurrently creating an infrastructure industry that contributes to the society on a global basis necessitates formulation and implementation of multi-timescale—i.e., short-, medium-, and long-term—strategies which to integrate scientific/technological innovations with social and economic mechanisms. Energy creates extremely significant social impacts and legacy. Transformation of energy structures takes time. Short-, medium- and long-term transformations should be considered in terms of, respectively, 5 to 10 years, 10 to 20 years and 20 to 100 years. It is necessary to make continuous investment beyond boundaries of industries, academic disciplines, and generations based on industry-academia-government cooperation and thereby to develop individuals who will be capable of discussing energy systems from multiple angles and assume continuous responsibilities for relevant initiatives.

Relevant academic disciplines would include not only electric, transportation, information and other engineering areas but also economics, business administration, financial engineering and sociology, which to cross over each other. At universities, a joint education and research program concerning energy systems can be set up beyond the boundaries of graduate schools' specialization or departments. The program will develop capabilities to consider various issues in the society with increasing complexity from an objective, panoramic perspective, to identify, formulate and solve problems, and to identify truly important challenges on a multi-timescale basis from the perspective of both interdisciplinary and multiple time horizons—short-, medium- and long-terms. In such initiatives, an effective approach would be, for example, to set up and implement a project that seeks to solve an energy system issue by combining expertise from different disciplines, where research and capacity building are concurrently pursued. Also, the project's achievements can be utilized for innovations and development of a new industry. Furthermore, a system development project could lead to creation and development of new interdisciplinary knowledge, methodologies and tools. Maximizing the effectiveness of these initiatives necessitates strong collaboration and cooperation between universities and the industrial sector. Furthermore, the industrial sector should develop a system for adequately accepting these individuals who receive such crossover education and seek to work in the industrial sector.

Furthermore, the said approach to human resources development differs significantly from the universities' conventional approach that seeks to develop individuals who would be competitive in the international academic world. Therefore, it is also necessary to develop evaluation criteria relevant for the new human resources development approach. Evaluation criteria could place emphases on social or economic values of results produced by the individual and on the process for linking the research outcome to value creation. They could positively evaluate application of knowledge and organizational management capability.

The above-described human resources development will be mainly led by the industrial sector and universities. Furthermore, although short-term tasks will be determined by market mechanisms, human resources development to respond to medium and long-term challenges should entail national perspectives and policies. An important role should be assumed by universities given their long-term perspectives and approaches. Therefore, the government's support for the universities is imperative.

5.2 Utilization of senior personnel

Japan's population is rapidly aging with the declining number of children. Formulating and implementing energy systems-related strategies on a multi-timescale basis should entail proactive utilization of industry-ready senior personnel, important assets, thereby accelerating the development of local community systems and bulk power systems. In Japan today, a huge number of experienced personnel, who have supported highly-credible energy supply, are approaching their retirement ages. Japanese companies face the issue of technological succession, which is causing a concern about a future decline of technological capabilities. On the other hand, overseas companies are proactively hiring senior Japanese personnel, thereby enhancing their technological capabilities. For the purpose of securing appropriate personnel for the changing energy systems in a range of functions, it is desirable to develop a pool of senior personnel beyond the boundaries of individual companies. At the same time, integration of technological standards, which currently vary by companies, would be important from the perspective of securing personnel in the age of declining population with a declining number of children. It is especially important to utilize senior personnel as innovators who help establish the connection among the industry, the academia and the government for the local community that will address new challenges.

Chapter 6: Conclusion

(1) Overview of the energy systems

In Society 5.0, individuals will play the key roles in daily living. Unique energy systems will be developed by local communities. Data will play important roles. Not only electricity but new values and services will be provided. The bulk power systems will play an important role for improving the entire society's "3E+S." The local communities' and the bulk power systems' roles will no longer be standardized; they will be restructured and coexist. An exponential increase in factors requiring collaborations and coordination—including distributed energy sources, linkage between the bulk power systems and many local communities and human behaviors—necessitates establishment of a new collaborative mechanism that integrate these distributed resources. We will seek to realize the vision for energy systems by sharing data and anticipation for the fusion of real and cyber spaces, discussing with a range of stakeholders, and utilizing Japan's technological competitiveness and accumulated human resources.

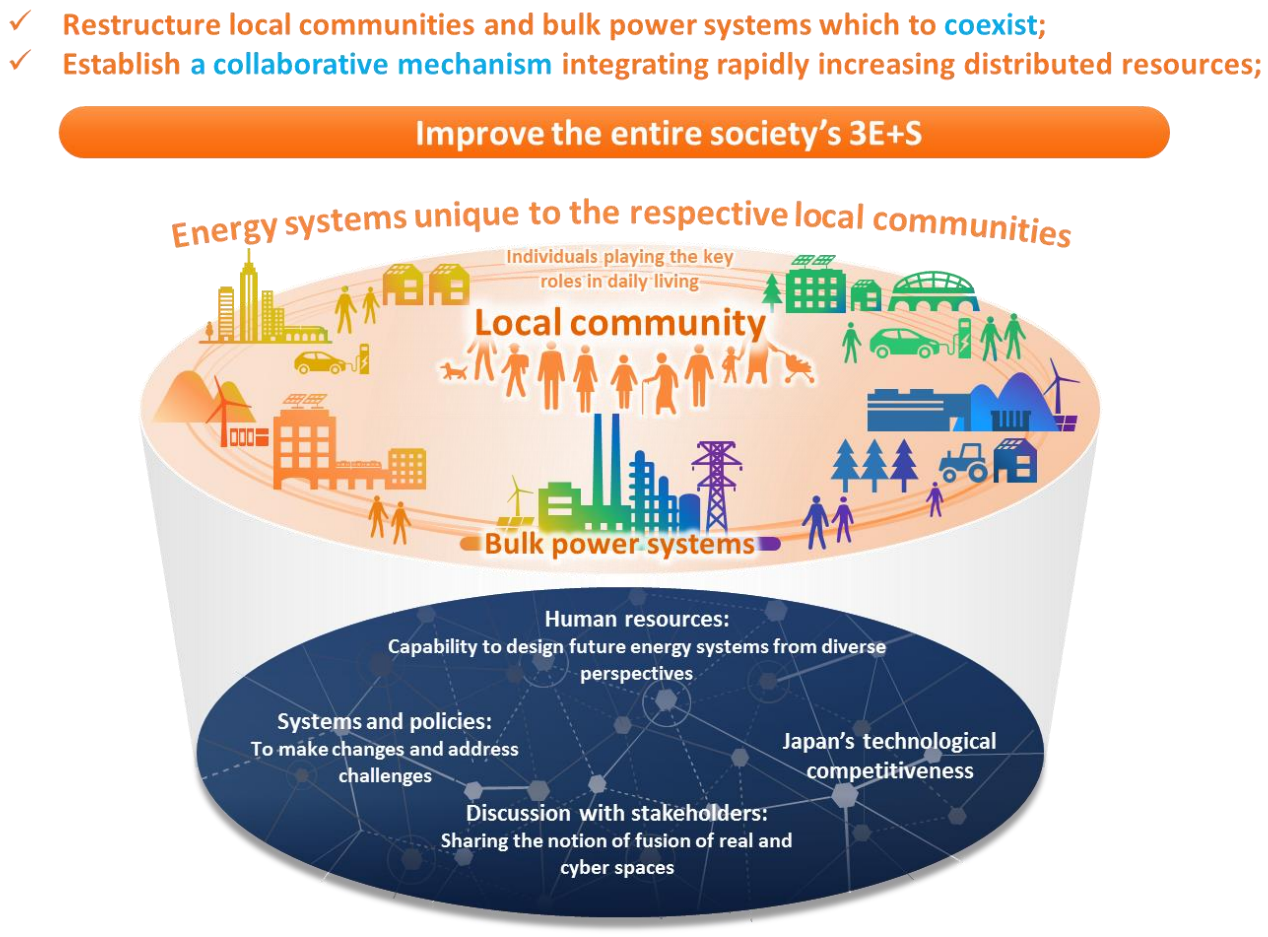

Fig. 15: Overview of energy systems to support Society 5.0

(2) New directions of challenges to be addressed by the local communities

While energy values get increasingly diversified, local communities should pursue technological innovations and improve their systems to create, distribute and trade unique values. For example, in the case of a region suitable for renewable energy generation, the local community should develop and implement initiatives for stabilizing the electricity systems and, concurrently, seek to foster local industries, utilizing excess electricity. Developing a public system for sharing information of various infrastructures—including not only electricity, gas, and water but ICT, automobiles and logistics—would facilitate creation of new services and businesses. Redevelopment of a city and a city block should be strategic redevelopment of infrastructure based on benchmarking and sharing of energy and environment performance of the city and the city block and adequate incentives, focusing on social values that the local community pursues from the perspectives of people's daily living and industrial structures beyond the scope of specific equipment or buildings.

(3) Framework to support the changes in the bulk power systems

Discussing a vision for bulk power systems necessitates development of a platform for evaluating the entire society's energy systems including electricity. The industry, the academia and the government should cooperate to develop and share analytical tools and standard data. Discussions among various stakeholders based on the evaluation results should lead to a social consensus concerning the roles of the bulk power systems and investment for relevant transformation. Furthermore, new controlling technologies for digitally connecting the bulk power systems with the local communities should be incorporated and utilized. Such technologies and relevant experiences will be globally rolled out.

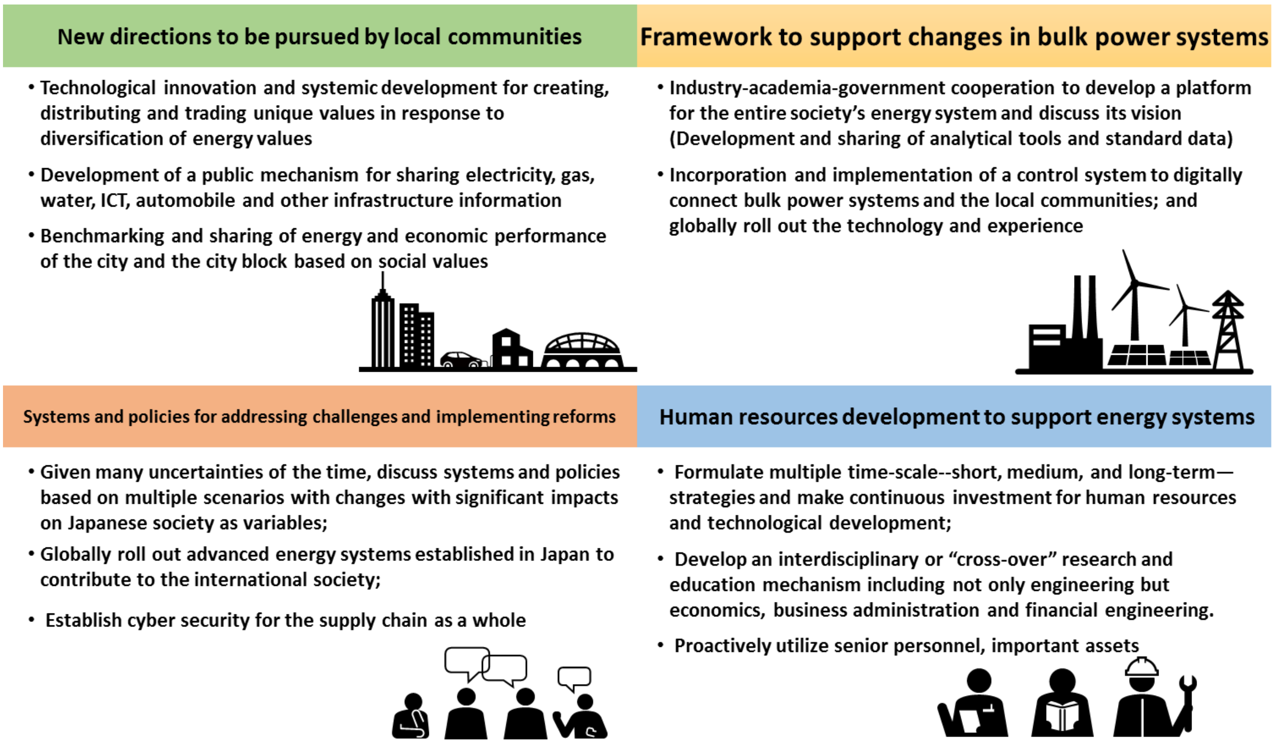

Fig. 16: Tasks toward realizing energy systems supporting Society 5.0

(4) Systems and policies for addressing the challenges and realizing transformation

In this period of significant uncertainties including political and economic situations and technological innovations, systems and policies should be discussed based on multiple scenarios with factors with significant impacts on Japanese society as variables. Outcomes of innovations and investments should be evaluated from multiple perspectives including economic efficiency, environment and energy security. PDCA should be implemented. Advanced energy systems established in Japan will be rolled out globally, making contributions to the international society. Concurrently with the discussions on policies and systems, consideration of operational aspects is also needed, including investments for export of infrastructures and overall supply chain security and governance.

(5) Development of human resources and technologies for supporting the energy systems

Developing energy systems necessitate formulation of strategies on a multi-time scale basis—short, medium and long-term. Especially, continuous investment for developing human resources and technologies is imperative. Interdisciplinary or “crossover” research and education systems should be set up—including not only electricity, transportation, information and other engineering fields but also economics, business administration, financial engineering and sociology—to foster individuals who are capable of designing future energy systems from broad perspectives integrating science and technology, social systems and economic mechanism. Also, we should proactively utilize senior personnel, important assets, to accelerate the development of local communities and bulk power systems.

End of Document

Members considering the proposal

1. The University of Tokyo

Toshihiko Koseki	Overall supervision	Executive Vice President
Shinobu Yoshimura	Coordinator; WG0	Vice President; and Professor, Graduate School of Engineering
Ichiro Sakata	WG0	Special Advisor to the President; and Professor, Graduate School of Engineering
Akihiko Yokoyama	WG1	Professor, Graduate School of Frontier Sciences
Ryuji Matsuhashi	WG1	Professor, Graduate School of Engineering
Kazuhiko Ogimoto	WG2	Project Professor, Institute of Industrial Science
Esaki Hiroshi	WG2 and 3	Professor, Graduate School of Information Science and Technology
Kenji Tanaka	WG2	Project Associate Professor, Graduate School of Engineering
Hiroshi Ohashi	WG3	Professor, Graduate School of Economics
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Tetsuya Okubo	Secretariat	University Corporate Relations Department
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Masahiro Watanabe	WG1	Chief Researcher, Center for Technology Innovation - Energy, Research & Development Group
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Satoru Akasaka	WG3	Researcher, Hitachi Research Institute
Osamu Kamimura	Secretariat	Senior Engineer, Technology Strategy Office, Research & Development Group
Nao Saito	Secretariat	Senior Engineer, Technology Strategy Office, Research & Development Group

WGs refer to the following working group:

WG0: Overall vision; WG1: Bulk power systems; WG2: Local communities; WG3: Systems and policies

Name of each WG's leader is underlined.