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Managing uncertainty in an era of increasing power demand : Towards the realization of S+3E

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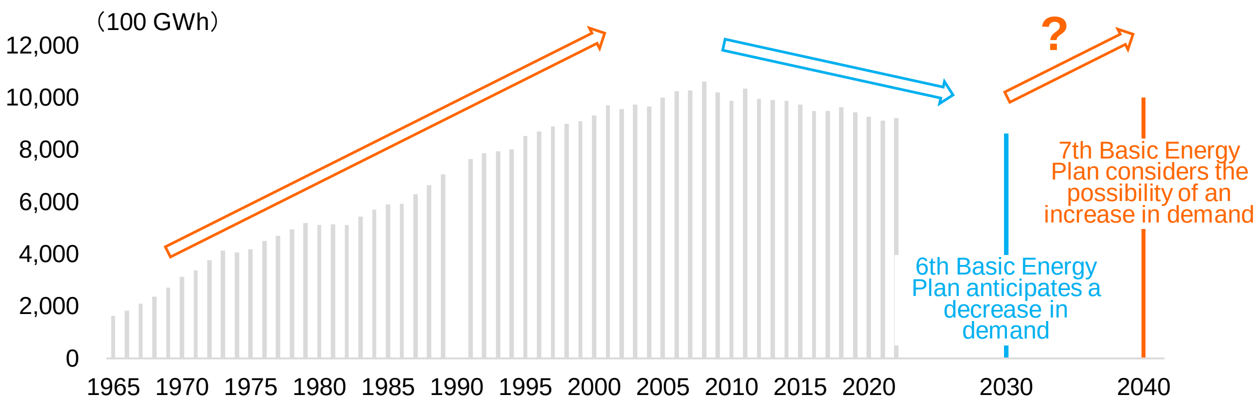
Executive Summary

- With the proliferation of generative AI and the advancement of industrial electrification, future power demand is expected to follow an increasing trend. However, the extent of this increase in power demand is subject to significant uncertainty due to a complex interplay of factors such as societal changes and the pace of technological innovation. In this context, achieving S+3E principles (Safety plus Energy security, Economic efficiency, and Environmental sustainability) in the power system requires a comprehensive approach that considers the characteristics of each type of power source.
- In the short term, rapid demand increases from data centers and semiconductor factories necessitate the swift securing of supply capacity through the utilization of dormant power sources and the development of renewable energy. In the long term, the development of zero-emission thermal, nuclear, and geothermal power, which involves various risks such as long construction lead times and extended total project durations, is anticipated to progress sufficiently.

While power demand in Japan showed an increasing trend from 1965 to 2008, it has declined since 2009 due to economic and energy crises such as the global financial crisis and the Great East Japan Earthquake in 2011, as well as the strengthening of measures against global warming. The 6th Basic Energy Plan, issued in October 2021, anticipated a 6.5% decrease in power demand by FY2030 compared to FY2021, considering factors such as the promotion of thorough energy conservation and population decline, which outweigh the demand-increasing factors of economic growth and improved electrification rates. Nevertheless, there is a growing view that power demand will increase for the first time in approximately 15 years due to the accelerated establishment of data centers (DCs) and the electrification of industries. The governmental committee that deliberates and examines the next Basic Energy Plan (7th Basic Energy Plan) is also progressing with considerations based on the potential increase in power demand (Figure 1).

Figure 1: Trends in Power Demand and Projections in the Basic Energy Plans



(Note) Created by DBJ based on the "Annual Report on Energy for FY2023" by the Ministry of Economy, Trade and Industry, etc.

In this report, we aim to explore future power demand in Japan, which forms the basis for energy policy formulation, by examining projections published by various organizations, results from our interviews, and the "Survey on Planned Capital Spending for FY2024" published by our bank in August 2024 (DBJ Survey). We will then consider realistic approaches to achieving Safety plus Energy security, Economic efficiency, and Environmental sustainability (S+3E) in the power system, based on the characteristics of each type of power source.

1. Future Power Demand Projections

1.1. Projections by External Organizations

Japan's power demand has been on a declining trend since peaking in FY2008, primarily due to advancements in energy conservation. However, many organizations predict a significant increase in power demand towards 2050, driven by the progress of digitalization and electrification (Figure 1-1).

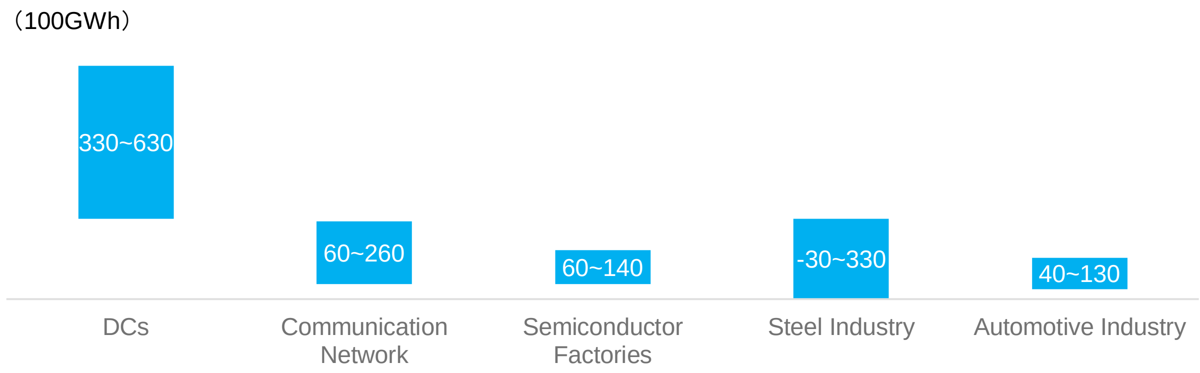
Figure 1-1: Projections of Power Demand in 2050 by Major Organizations

Forecasting Organization	Publication Date	Estimated Amount	Increase/ Decrease since 2022	Notes
OCCTO	Mar 2023	Demand: **1.25** million GWh	+35%	Calculated during the formulation of the regional interconnection system master plan.
IEEJ	Oct 2024	Generation: **1.09** million GWh	+8%	Refer to the "Reference Scenario" calculated based on current technology and policies in IEEJ Outlook 2024.
IEA	Oct 2024	Generation: **1.35** million GWh	+33%	Analysis results in the World Energy Outlook 2024 APS (Announced Pledges Scenario).
CRIEPI	Mar 2024	Demand: **1.07** million GWh	+10%	Refer to the "mid" case calculated in the 4th discussion on future power supply and demand scenarios by OCCTO.
RITE	Jan 2024	Demand: **1.15** million GWh	+25%	Refer to the "baseline" case calculated in the 3rd discussion on future power supply and demand scenarios by OCCTO.

(Notes)
1. Created by DBJ based on various sources.
2. OCCTO stands for Organization for Cross-regional Coordination of Transmission Operators; IEEJ stands for The Institute of Energy Economics, Japan; IEA stands for International Energy Agency; CRIEPI stands for Central Research Institute of Electric Power Industry; and RITE stands for Research Institute of Innovative Technology for the Earth.
3. Due to transmission losses and other factors, the amount of generated electricity is estimated to be greater than the amount of demand.

In the "Study Group on Future Power Supply and Demand Scenarios" held by the Organization for Cross-regional Coordination of Transmission Operators (OCCTO), the power demand estimates for 2040 and 2050 regarding planned power source development, highlighted several key factors contributing to future demand increases. These factors include DCs and communication networks centered around base stations; the establishment of new semiconductor factories; the steel industry, considering the use of electric furnaces; and the automotive industry advancing electrification (Figure 1-2). In the next section, we will analyze the trends in various sectors that impact power demand, incorporating findings from DBJ Survey.

Figure 1-2: URAYASU Assumed Demand Increase in Key Industries and Sectors in the Study Group



(Note) Created by DBJ based on the "Study Group on Future Power Supply and Demand Scenarios" by OCCTO.

1.2. Investment Trends in Key Industries and Sectors

1.2.1. Expansion of Digital Infrastructure (DCs, Communication Networks, Semiconductors)

With the recent progress in digitalization, an increase in power demand is expected for digital infrastructure such as DCs and communication networks, as well as for the manufacturing of semiconductors, which are key components of digitalization. Generally, digital infrastructure requires 24/7 operation, necessitating a stable power supply.

In DCs, significant power demand arises from the operation of servers composed of CPUs, memory, and storage, as well as cooling equipment to suppress the heat generated by these devices. While the construction of new DCs primarily used to focus on cloud applications with capacities of tens of megawatts, the proliferation of generative AI, which requires substantial data processing for both model training and inference, is expected to lead to the establishment of new DCs with capacities ranging from several hundred MW to several GW. As the performance of generative AI improves with larger parameter counts and more training data, the computational load for training is doubling approximately every three to four months, leading to an anticipated increase in required power.

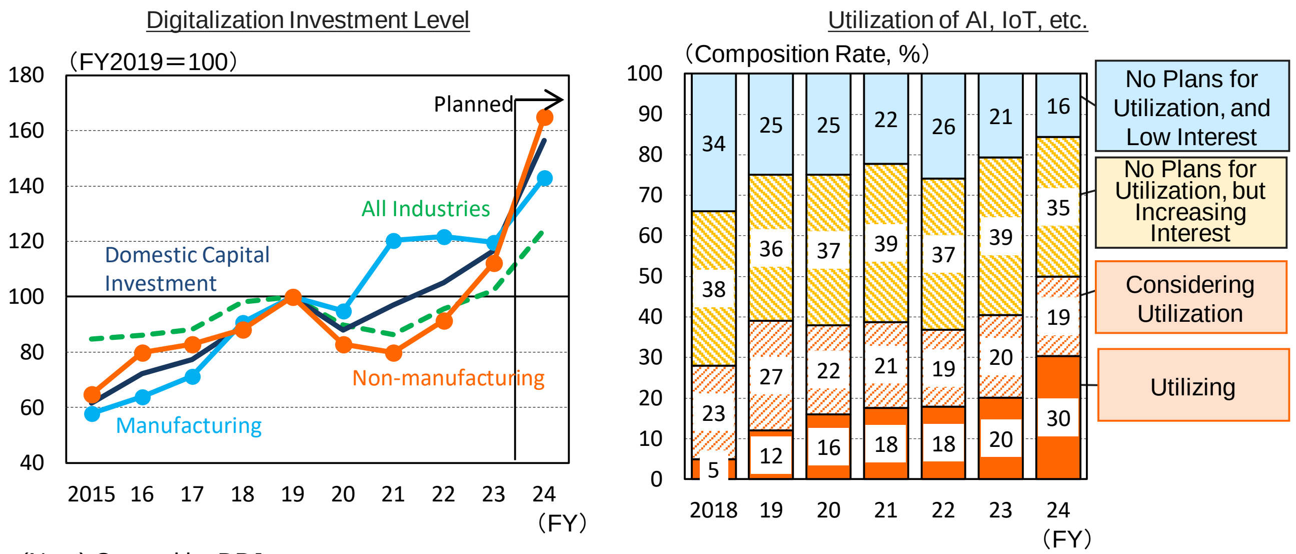
For communication networks, power demand is also expected to increase due to the rise in communication volume driven by the spread of the IoT. Additionally, the recently introduced 5G networks, which use high-frequency bands with shorter transmission ranges, require the installation of more base stations, further contributing to increased power demand. The Japan Science and Technology Agency (JST) estimates that with the further adoption of the IoT and generative AI, power demand in communication networks will increase from 23 billion kWh in 2018 to over 100 billion kWh by 2030.

However, despite the exponential increase in data processing volumes, technological innovations such as semiconductor integration have kept the increase in power demand within certain limits. Future advancements in semiconductor design, server cooling methods, and the utilization of photonic-electronic convergence technologies, as proposed in NTT's IOWN initiative, may further suppress the initially anticipated increase in power demand.

Additionally, with the increasing demand and societal importance of semiconductors, large-scale investment projects are being planned across Japan, supported by government initiatives. Notable examples include JASM in Kumamoto Prefecture and Rapidus in Hokkaido. The establishment of new semiconductor factories is a significant factor contributing to the increase in power demand. Furthermore, as semiconductors become more miniaturized, the power demand for exposure equipment that etches fine circuit patterns onto silicon wafers is also increasing. Extreme ultraviolet (EUV) lithography equipment, which is planned to be introduced at facilities such as Rapidus and Micron Technology's Hiroshima plant, is another factor driving up power demand.

According to DBJ Survey, investments in digitalization have increased for three consecutive years since FY2021, with even higher growth projected for FY2024 (Figure 1-3, left). Additionally, the degree of utilization and consideration of AI and the IoT has been rising year by year (Figure 1-3, right). In the semiconductor sector, active investment plans have been confirmed across a wide range of areas, from foundries to manufacturing equipment makers and component material manufacturers.

Figure 1-3: Trends in Digitalization Investments and Utilization of AI and IoT by Large Corporations



(Note) Created by DBJ.

1.2.2. Industrial Transformation Towards Decarbonization

(Utilization of Electric Furnaces in Steelmaking, Electrification of Automobiles)

A significant industrial transformation that could greatly impact power demand in the mid term is the expanded use of electric furnaces in the steel industry and the electrification of automobiles. The steel industry is a major emitter, accounting for about 40% of CO2 emissions in the industrial sector in Japan, with much of these emissions arising from the blast furnace process that uses coal as a reducing agent. One of the strategies for future decarbonization is the expanded use of electric furnaces. Not only traditional electric furnace manufacturers but also the three major companies that have primarily operated blast furnaces (Nippon Steel, JFE Steel, and Kobe Steel) are planning new installations and enhancements of electric furnaces (Figure 1-4).

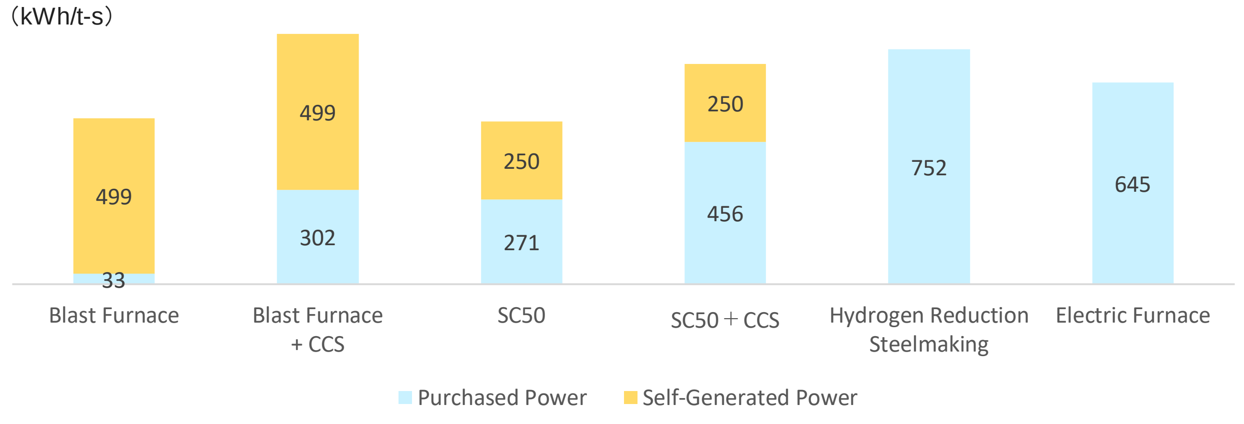
Figure 1-4: Electric Furnace Plans of the Three Major Blast Furnace Companies

Company	Location	Target Date	Notes
Nippon Steel	Hasaki R&D Center	2024	Demonstration with a small electric furnace
Nippon Steel	Setouchi Works (Hirohata area)	2030	Expansion of electric furnace for electromagnetic steel sheets
Nippon Steel	Kyushu Works (Yawata area)	2030	Planned conversion of one blast furnace to an electric furnace
JFE	East Japan Works (Chiba area)	2024 – 2025	Demonstration with a small electric furnace
JFE	West Japan Works (Kurashiki area)	2027 – 2030	Planned conversion of one blast furnace to an electric furnace
JFE	Sendai Works	2024	Enhancement of existing electric furnace
Kobe Steel	Kakogawa Works	2030 –	Considering conversion of blast furnace to electric furnace

(Note) Created by DBJ based on various sources.

The electric furnace method has a higher unit power consumption compared to the blast furnace method. Additionally, while the blast furnace method has a high self-sufficiency rate for power due to the use of by-product gas for self-generation, the electric furnace method does not produce by-product gas and thus relies on purchasing power from the grid. Therefore, converting blast furnaces to electric furnaces requires large-scale external power procurement and the development of transmission and distribution networks (Figure 1-5). Currently, some companies are implementing demand response (DR), which involves operating electric furnaces during periods when there is a surplus of power generated from renewable energy. Although such initiatives are expected to continue for the efficient operation of the power system, ensuring stable power procurement is a prerequisite for achieving large-scale and stable crude steel production with electric furnaces.

Figure 1-5: Power Consumption per Unit for Each Steelmaking Process



(Notes)
1. Created by the DBJ based on materials from Nippon Steel Research Institute (currently Nippon Steel Technology).
2. "SC50" is a technology that reduces CO2 emissions by using hydrogen for the reduction reaction, while still based on the blast furnace method.

To expand the use of electric furnaces, securing scrap materials as raw materials and developing technologies for manufacturing high-performance materials remain challenges. Although specific plans have not yet appeared in the latest DBJ Survey, investment decisions need to be made in the coming years to achieve full-scale operation around 2030. Furthermore, since newly operational electric furnaces will continue to operate for several decades, improving the predictability of securing cheap and stable power over the decades following 2030 is essential to encourage investment decisions by businesses.

The electrification of automobiles is also expected to have a certain impact on power consumption, both during manufacturing and during use for charging. Although short-term stagnation and setbacks may occur, the long-term trend towards 2040 and 2050 remains unchanged. The composition ratio of electric vehicles (EVs) and plug-in hybrid vehicles (PHEVs) is expected to increase from the current structure centered on gasoline and hybrid vehicles. The Japanese government is also implementing and planning subsidies for the construction of factories for storage batteries and related materials, which are key components of EVs, within the framework of economic security. According to DBJ Survey, companies from a wide range of industries have reported active capital investment plans to respond to the electrification of automobiles.

While there are projections of increases in power demand across various sectors, the extent of the increase in power demand is subject to significant uncertainty due to a complex interplay of factors such as societal changes, the pace of technological innovation, and the development of the power supply system. <u>This uncertainty represents a critical issue concerning future power demand.</u>

2. Comments from External Experts

Based on the trends in various industries and sectors discussed in the previous section, interviews were conducted with several external experts regarding their views on future power demand and matters that require attention.

The Federation of Electric Power Companies of Japan pointed out that while an increase in power demand is expected due to the progress of electrification and digitalization in the industrial, transportation, and household sectors, there is still a lot of uncertainty regarding the extent and timing of this increase. Therefore, <u>it is necessary to consider scenarios with a certain degree of flexibility</u>. Specifically, regarding power demand linked to the progress of digitalization, they foresee an explosive increase in data processing in DCs and communication volumes in communication networks. However, they also noted the potential for power savings per unit of data processing and communication due to various innovative technologies, making it essential to assess the extent of the increase.

Additionally, Mr. Kaname Ogawa, Director of the Policy Division of the Electricity and Gas Industry Department at the Agency for Natural Resources and Energy, noted the urgent need to secure supply capacity for DCs. He mentioned that, in conjunction with the construction and location plans for DCs, demand forecasts for each period and area have been rapidly changing since last year. Therefore, it is necessary for the entire supply chain, including power generation and transmission and distribution (T&D) operators, as well as various equipment and material manufacturers, to respond to the increase in power demand with a sense of urgency.

Sumiko Takeuchi, Director and Chief Researcher at the International Environment and Economy Institute, emphasized the importance of recognizing the gap between the realistically discussed Basic Energy Plan and Long-term Energy Supply and Demand Outlook (forecast) and the idealistically set nationally determined contributions (NDCs) (backcast). She pointed out that it is crucial to have a risk management perspective in energy policy formulation. As the 7th Basic Energy Plan is being developed, she stressed the need for a thorough discussion on the stable supply of energy, the improvement of the business environment for nuclear power utilization, and the securing of fossil fuels as strategic resources. She also mentioned that achieving carbon neutrality would require cost burdens and stricter regulations. Additionally, she raised the issue of the mismatch between the investment recovery periods for power-consuming facilities like DCs and T&D facilities.

Other experts, including power consumers from various industries and researchers, also commented that despite various uncertainties, the main scenario is an increase in power demand. They emphasized the need for various measures to build a stable supply system, which is essential for maintaining and enhancing industrial competitiveness.

3. Ensuring Supply Capacity for the Realization of S+3E

As discussed in the previous section, power demand is expected to increase due to the progress of digitalization and electrification, making it crucial to secure supply capacity to maintain a stable supply system. However, excessive investment in power sources can lead to a decrease in facility utilization rates, necessitating strategic development of the power system and institutional design that balances economic rationality and stable supply. This section will explore the future approach to realizing S+3E in the power system (Figure 3).

In the short term, it is expected that supply capacity will be swiftly secured to address the rapidly increasing demand from DCs and semiconductor factories. On the other hand, in the long term, aiming for carbon neutrality, the development of zero-emission thermal, nuclear, and geothermal power, which are necessary for building an energy mix but involve various risks such as long construction lead times and overall project durations, is anticipated. Considering these different timeframes, a comprehensive approach that takes into account the characteristics of each type of power source is required.

Figure 3: Chronological Changes in the Power System and Measures to Secure Supply Capacity

	Era of Comprehensive Cost-Based Pricing	Era of Power Liberalization		
	1965～2008	2009～2023	2024～2030	2031～2050
Demand	Increase Due to Economic Growth	Decrease Due to Energy Conservation	Increase Due to Digitalization, etc.	
DR		Expansion of DR for High and Extra-High Voltage → Expansion of DR for Low Voltage, Using Digital Technology →		
T&D	Strengthening of T&D Networks through Comprehensive Cost-Based Pricing →	Refinement and Publication of Power Demand Forecasts → Strengthening of T&D Networks through Revenue Cap Method →		
Solar and Wind Power		Large-Scale Introduction through FIT / FIP Systems →	Additional Introduction through Innovative Technology →	
Geothermal	Development in Suitable Locations	Support for Introduction through FIT / FIP Systems → Expansion of Introduction through Policy Support and Innovative Technology →		
Thermal & Nuclear power (common)	Development Based on Comprehensive Cost-Based Pricing	Improvement of Predictability through Long-term Decarbonized Power Auctions →	Risk Sharing Among Private Sector Operators →	
Thermal Power		Strategic Fuel Procurement → Securing Standby Power →		
Nuclear Power		Restarting Plants Based on Safety and Local Consent →		

（Note）Created by DBJ.

3.1. Demand-Side Measures (Utilization of Energy-Saving Technologies and DR)

To ensure economically rational supply capacity in the power system, efforts on the demand side are also important, in addition to those on the supply side. On the demand side, in addition to technological innovations that suppress power demand as mentioned earlier, there is also high expectation for DR to curb peak power demand. For DR, it is important to maximize its potential not only for extra-high voltage and high voltage but also for low voltage with a considerable scale, through the automation of the DR process (automated DR [ADR]).

3.2. Development of T&D Networks

Regarding T&D networks, in addition to the much-discussed strengthening for the introduction of renewable energy and the maintenance and updating of aging facilities, it is also necessary to develop networks flexibly to respond to localized increases in power demand.

The revenue cap system, introduced in 2023 to achieve economically rational investments in T&D networks, allows T&D operators to consider supply measures and carry out construction based on connection applications from consumers. However, this pull-type approach may not be sufficient to respond to the rapid power demand from DCs and semiconductor factories. Therefore, it is also important to consider transitioning to a push-type system formation that connects power plants and demand areas in a planned manner, considering the potential of power sources.

In addition to the supply plans published annually, it is expected that by considering appropriate information exchange among various stakeholders, including power generation, T&D, retail operators, and large consumers, the predictability of each company's business plans will be improved.

3.3. Securing Supply Capacity through Renewable Energy

Solar and wind power, with short construction periods of three to five years and expected contributions to achieving carbon neutrality, are important short-term measures for securing supply capacity. However, in Japan, a considerable amount of solar and wind power has already been introduced, and suitable locations for additional installations are limited. Therefore, the use of innovative technologies is crucial for further expansion. In solar power, perovskite solar cells, which are lightweight and flexible, can be installed in various locations such as building facades and roofs with low load-bearing capacity. In wind power, floating offshore wind turbines, which are less affected by water depth, are attracting attention for development in areas with stable wind conditions, including Japan's vast exclusive economic zone (EEZ). However, since the power generation of solar and wind power is influenced by seasons and weather, the introduction of storage batteries and long-duration energy storage (LDES) technologies is also important to improve reliability.

Geothermal power is a stable renewable energy source that is not affected by seasons or weather, and Japan has the third-largest geothermal resource in the world (approximately 23.4 GW), making it an important power source for achieving Japan's S+3E goals. However, the lead time to operation is long, and there are significant development risks such as drilling for geothermal resources. Additionally, obtaining permits in national and quasi-national parks, where 80% of geothermal resources are located, is not easy, and coordination with local stakeholders such as hot spring operators is challenging, resulting in insufficient progress in its introduction. The government has already been working on expanding support measures through Japan Oil, Gas and Metals National Corporation (JOGMEC) and regulatory reforms, but further measures to reduce risks for businesses, such as a central approach where the government and local authorities take the lead in project formation, could also be considered. Furthermore, existing geothermal power plants require suitable locations that meet three conditions—high heat sources, abundant water, and permeable rocks—making development difficult. Therefore, the use of innovative technologies such as enhanced geothermal systems (EGS) is also expected.

3.4. Securing Short-Term Supply Capacity through Thermal and Nuclear Power

To address short-term, uncertain or sudden increases in demand, such as extreme weather conditions or the establishment of new DCs, the utilization of existing thermal and nuclear power plants is important. As a measure to secure short-term supply capacity, mechanisms such as additional auctions in the capacity market, conducted one year before the actual supply–demand year, and additional kW tenders to address supply shortages in summer and winter have already been established. Additionally, starting this fiscal year, a reserve power system has been introduced, positioning standby power sources as "quasi-supply capacity" and covering the maintenance costs of standby thermal power plants that did not bid or whose bids were not awarded in the capacity market.

On the other hand, the predictability of the operating rates of thermal power plants has decreased due to the large-scale introduction of renewable energy and liberalization of the market, making the stable procurement of fuel a challenge. In 2021, the government formulated guidelines urging businesses to secure appropriate inventory levels and make efforts to procure fuel. Although these guidelines primarily focus on LNG-fired power, the future reserve power system aims to utilize oil-fired power plants, which are being decommissioned due to low economic viability, during power supply–demand tightness. Therefore, it is also necessary to secure oil and maintain the oil supply chain in preparation for emergencies. Continued strategic efforts involving both the public and private sectors are crucial for securing fuel, and it is hoped that the government will secure a certain amount of fuel, collaborate with fuel-consuming countries like South Korea, and expand international fuel trading to reduce the risks borne by each business.

Regarding the restart of nuclear power plants, the "Basic Policy for the Realization of GX," issued in 2023, states that the restart of reactors that have passed the Nuclear Regulation Authority's inspections and obtained local consent will be promoted, with safety as the top priority. Restarted nuclear power plants are expected to be a short-term measure to secure supply capacity.

3.5. Securing Long-Term Supply Capacity through New Power Source Investments

Under the past comprehensive cost-based pricing system, former general electric utilities in each area made long-term, planned large-scale power source investments to meet the increasing power demand driven by economic growth. However, in the current era of power liberalization, power source investments are promoted through market mechanisms. While such market mechanisms can potentially optimize across regions, they are inferior to the comprehensive cost-based pricing system in terms of the predictability of medium- to long-term revenues. This could lead to a future shortage of supply capacity. Therefore, as a type of special auction in the capacity market, a long-term decarbonized power source auction was established last year. This system fixes capacity revenues for 20 years to ensure that businesses can secure capacity revenues at the level of fixed costs and a pre-tax weighted average cost of capital of 5%, thereby enhancing the predictability of investment recovery. However, since the business remuneration is uniform across power sources, high-risk power sources are less likely to be favored. It is desirable to secure profit margins according to the risks of each power source. For power sources that are highly important in the energy mix and carry significant risks for businesses, it may be worth considering a system like the UK's Regulated Asset Base (RAB) model, which allows for the recovery of investment costs, including cost increases after the start of construction, in a comprehensive cost-based manner during the construction period, thereby reducing the risks and financing costs for businesses.

Additionally, to undertake large-scale and high-risk power source development projects, appropriate risk diversification among the public sector, private sector, and financial institutions is required. Particularly, given the financial constraints on power companies due to power liberalization and preparations for restarts of nuclear power, it is important for power companies and various stakeholders to establish special purpose companies (SPCs) for projects like offshore wind power, sharing the risks associated with power source development among the participants. In such cases, SPCs can improve their revenue predictability and reduce financing costs by entering long-term bilateral contracts with end-users such as DC operators and major telecommunications companies. The Mankala model in Finland, where power is provided on a cost basis according to the shareholders' investment amounts, is also noteworthy as a joint ownership power development model. Financial institutions are expected to contribute risk capital not only through corporate finance but also through project finance and equity investments, sharing risks alongside the business companies.

4. Conclusion

Currently, as energy transition towards achieving carbon neutrality is required, the first increase in power demand since the liberalization of the electricity market is predicted, making the realization of S+3E in the power system challenging. Therefore, in addition to existing initiatives, in the short term, the utilization of standby power sources and the introduction of renewable energy through innovative technologies are expected. In the long term, securing supply capacity through the promotion of new power source investments with risk diversification among various stakeholders is anticipated.

Gratitude is extended to the named and unnamed experts who contributed to the writing of this report.

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