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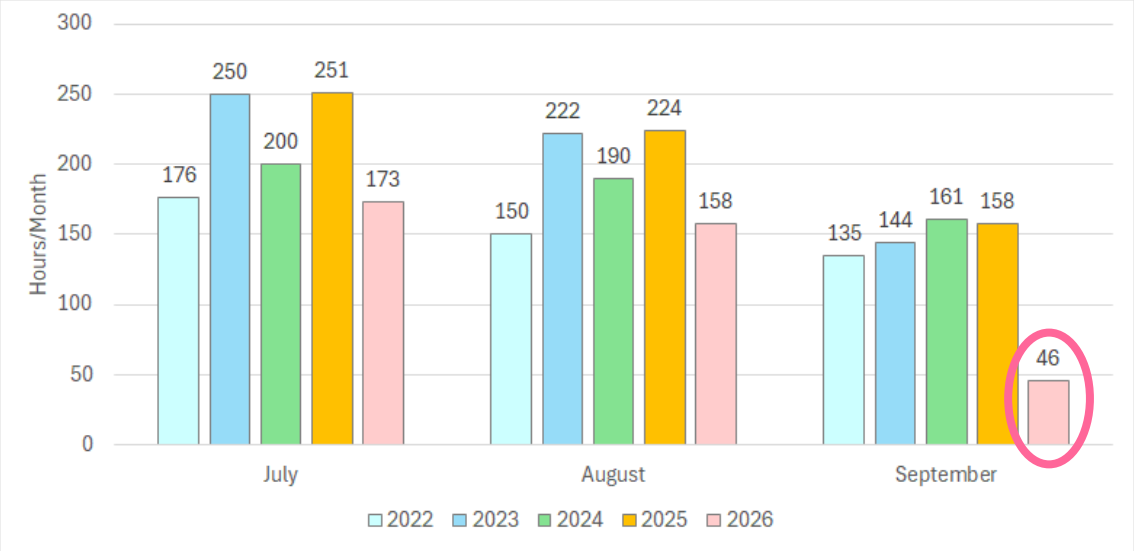
Ensuring Adequate Generation Capacity During Prolonged Periods of Low Variable Renewable Energy Output

— Addressing Dunkelflaute and Utilizing Existing Thermal Power Plants as Strategic Reserves —

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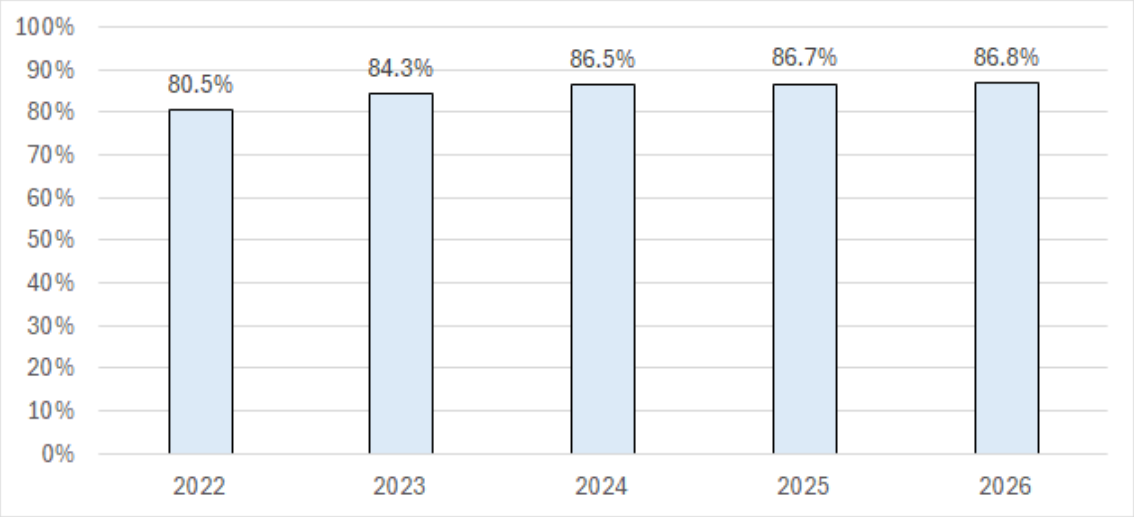
In recent years, Japan has seen increasing deployment of variable renewable energy (VRE) sources, particularly solar photovoltaic (PV) and wind power. Because electricity generation from these sources fluctuates significantly depending on weather conditions, ensuring adequate generation capacity during prolonged periods of low output has become an increasingly important challenge as their deployment expands. In September 2026, Tokyo experienced a period of persistent rainy and cloudy weather, during which sunshine duration declined substantially compared with the historical average, resulting in unfavorable solar irradiation conditions for PV generation (see Figure 1). However, this period occurred after the peak summer electricity demand season, and the decline in solar PV output did not immediately lead to severe supply-demand tightness (see Figure 2). Nevertheless, if similar weather conditions were to occur during periods of high heating or cooling demand, accompanied by simultaneous declines in solar PV and wind power output across a wide geographical area, ensuring adequate generation capacity could become more difficult. Given the prospect of further expansion of VRE deployment, it is necessary to consider measures in advance to address such prolonged periods of low output.

Figure 1. Comparison of Monthly Sunshine Hours in Tokyo from July to September 2022–2026



Source: Prepared by IEEJ based on Japan Meteorological Agency (JMA). (n.d.). Download historical weather data. Retrieved October 17, 2026, from https://www.data.jma.go.jp/risk/obsdl/index.php.

Figure 2. Average Daily Electricity Supply Utilization Rate in the Tokyo Area in September 2022–2026



Note: The electricity supply utilization rate is calculated by dividing the actual maximum electricity demand on a given day by the available supply capacity at the time of peak demand. It represents the proportion of available supply capacity utilized to meet maximum demand. A higher utilization rate indicates a tighter electricity supply-demand balance.
Source: Prepared by IEEJ based on TEPCO Power Grid, Inc. (n.d.). Calendar of Actual Maximum Electricity Demand (Tokyo Area). Retrieved October 18, 2026, from https://www.tepco.co.jp/forecast/html/calendar-j.html.

Prolonged periods of low VRE output are known in Europe as "Dunkelflaute." This refers to a meteorological phenomenon in which low solar irradiation and weak wind conditions persist, causing simultaneous declines in solar PV and wind power generation. Germany's Federal Network Agency (Bundesnetzagentur) defines Dunkelflaute as a period during which the

combined output of wind and solar PV generation remains below 15% of their installed capacity for at least 48 consecutive hours[1]. In Europe, such events can have a significant impact on electricity supply-demand conditions, particularly in winter, when heating demand increases, daylight hours are shorter, and wind power output may decline across extensive geographical areas.

In November and December 2024, several Dunkelflaute events occurred in Germany and neighboring regions, during which wind and solar PV generation declined sharply and simultaneously, contributing to tight electricity supply-demand conditions and spikes in wholesale electricity prices. In Germany, day-ahead market prices exceeded EUR 300/MWh (approximately JPY 54/kWh) for 35 hours (approximately 2.4%) out of the total 1,464 hours in November and December 2024[2]. Of these, 34 hours were concentrated on November 5–7 and December 11–12. The highest price during this period reached EUR 936/MWh (approximately JPY 168/kWh). According to a joint investigation published in October 2025 by the Federal Network Agency and the Federal Cartel Office (Bundeskartellamt), nearly all available lignite-fired and hard coal-fired power plants were operating during the price spikes on November 6 and December 12, 2024, compensating for the shortfall in renewable generation. Although no power outages occurred during these periods and sufficient generation capacity was secured, these events demonstrated the essential role of dispatchable generation sources, including thermal power plants, in maintaining a stable electricity supply.

This challenge will become increasingly important as VRE deployment expands. In "Electricity 2025", the International Energy Agency (IEA) highlighted the importance of dispatchable generation, long-duration energy storage, demand-side flexibility, and interregional transmission interconnections in addressing periods when wind and solar PV output decline simultaneously[3].

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[1] Bundesnetzagentur & Bundeskartellamt. (2025). Results of the investigation into price peaks in short-term electricity trading in November and December 2024. https://www.bundesnetzagentur.de/DE/Fachthemen/ElektrizitaetundGas/Aktuelles/Strompreis/Preisspitzen_Untersuchung_e.html?nn=666514
"Based on historical generation time series, the Bundesnetzagentur defines dunkelflaute periods as situations in which the generating capacity of wind and PV installations is continuously less than 15% of their installed capacity over a period of at least 48 hours."

[2] Bundesnetzagentur & Bundeskartellamt. (2025)

[3] International Energy Agency (IEA). (2025). Electricity 2025: Analysis and Forecast to 2027. International Energy Agency. Retrieved October 17, 2026, from https://iea.blob.core.windows.net/assets/6b1447c8-1dee-41da-ab6b-5e87ae015351/Electricity2025.pdf
"Having sufficient (low-emissions) dispatchable capacity and long-duration storage, among other flexibility options such as demand-side flexibility and interconnections, is important to effectively manage such periods."

In particular, when weather-related reductions in generation persist for several days or longer, the challenge differs from managing short-term supply-demand fluctuations, as the energy shortfall itself must be compensated for over an extended period. Furthermore, because uncertainty remains regarding the effects of climate change on future wind conditions, solar irradiation, and seasonal variations in electricity demand, generation adequacy assessments should consider multiple severe weather scenarios rather than relying solely on historical meteorological data.

One potential measure for addressing such prolonged generation shortfalls is long-duration energy storage (LDES). LDES encompasses a range of technologies, including pumped-storage hydropower, redox flow batteries, compressed-air energy storage, thermal energy storage, and hydrogen-based storage systems. By storing energy over extended periods, these technologies are expected to enhance the power system's ability to manage fluctuations in VRE output. However, the degree of commercialization, capital costs, and siting requirements vary significantly across technologies, and economically deploying large-scale facilities capable of addressing electricity shortages lasting several days to several weeks remains challenging. In addition, LDES faces not only the issue of storage capacity but also the question of how the energy to be stored can be secured. LDES facilities store energy and supply it when needed; they do not themselves produce primary energy. Consequently, if a prolonged decline in VRE output limits the availability of electricity for recharging, maintaining electricity supply after stored energy has been depleted may become difficult. Therefore, although LDES represents a promising option for addressing these challenges, it should not be relied upon exclusively at the present stage. Rather, it needs to be combined with generation sources capable of sustaining electricity production over extended periods through fuel stockpiling.

From this perspective, utilizing existing coal-fired power plants and other thermal generation facilities as strategic reserves represents one possible option. Although coal-fired power plants are expected to be progressively retired or decommissioned as part of the transition toward decarbonization, they have the advantage of being able to store fuel on-site or at other storage locations. Provided that sufficient fuel inventories are maintained, these plants can continue generating electricity for a certain period without having to wait for additional natural gas procurement or a recovery in renewable generation. In particular, it is important to retain existing coal-fired power plants and other thermal generation facilities that operate for relatively few hours annually and cannot economically maintain their facilities solely through revenues earned in the regular wholesale electricity market, so that they can serve as emergency generation capacity.

Germany has established mechanisms relevant to this approach, including the capacity reserve (Kapazitätsreserve), which functions as a strategic reserve, and the grid reserve (Netzreserve), which is intended to support stable transmission system operation. Although these mechanisms differ in their objectives and activation conditions, both provide arrangements for securing generation facilities outside the regular electricity market. In particular, the Netzreserve allows coal-fired power plants and other generation facilities that have exited the market to be retained and dispatched when necessary, under the instructions of transmission system operators[4].

Meanwhile, Japan plans to develop new LNG-fired power plants and replace existing facilities with new LNG-fired generation capacity. These plants are also expected to play an important role in addressing prolonged declines in VRE output caused by Dunkelflaute. However, LNG-fired generation depends on the continuous procurement and transportation of fuel. If additional LNG procurement becomes difficult for an extended period due to geopolitical tensions, disruptions at production facilities in major gas-producing countries, or interruptions to maritime transportation routes, electricity generation may be constrained as fuel inventories decline[5]. In particular, if such LNG supply constraints were to coincide with a Dunkelflaute event lasting several weeks, the resulting combined risks could seriously affect the stability of electricity supply.

As a means of preparing these compound supply risks, one possible option is to utilize existing coal-fired and oil-fired power plants, which can stockpile fuel on-site or at other storage locations, as strategic reserves. Japan has already introduced a Reserve Power Source System (Yobi Dengen Seido) as a mechanism related to securing emergency generation capacity. However, the current system is primarily designed to enable suspended generation facilities to resume operation when needed, and maintaining readiness to commence generation within several days of an activation request is not explicitly established as a common requirement. Accordingly, future revisions to the system could consider requiring technically capable existing coal-fired and oil-fired power plants to maintain a state of readiness that enables them to commence generation within several days of an activation request. In addition, to prepare prolonged periods of low renewable

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[4] Bundesnetzagentur. (2024). Confirmation of electricity grid reserve capacity requirements. Bundesnetzagentur. Retrieved October 17, 2026, from https://www.bundesnetzagentur.de/SharedDocs/Pressemitteilungen/EN/2024/20240430_Netzreserve_Pb.html
"Old coal-fired power plants are no longer needed for the supply of electricity on the market. They are only used for a few hours in exceptional situations when necessary to stabilise network operations."

[5] Agency for Natural Resources and Energy. (2021). Trends in electricity supply and demand and market prices (Material 4-1, 29th Meeting of the Electricity and Gas Basic Policy Subcommittee, Electricity and Gas Industry Committee, Advisory Committee for Natural Resources and Energy). Retrieved October 18, 2026, from https://www.meti.go.jp/shingikai/enecho/denryoku_gas/denryoku_gas/pdf/029_04_01.pdf

generation, the system could require sufficient fuel inventories to sustain generation at a specified output level for approximately one month, for example. To limit maintenance and operating costs, another option would be to require short-notice startup capability only during seasons when the risk of electricity supply-demand tightness is particularly high. Furthermore, appropriate cost-recovery mechanisms would need to be established to compensate for the additional costs associated with maintaining operational readiness and fuel inventories.

As VRE deployment continues to expand, preparing prolonged periods of low generation output, such as Dunkelflaute, will become increasingly important. Although LDES and LNG-fired power plants are promising options for addressing these challenges, they may not be sufficient when prolonged electricity shortages coincide with fuel supply constraints. Japan has already introduced a Reserve Power Source System that provides a mechanism for retaining existing coal-fired and oil-fired power plants as emergency generation capacity. Going forward, however, it will be important to consider strengthening the system's requirements to address scenarios in which prolonged declines in renewable generation coincide with fuel supply constraints. Such measures could include maintaining the capability to commence generation within several days of an activation request and securing sufficient fuel inventories to sustain electricity generation over extended periods.

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