IEEJ Outlook 2027

—The Expanding Dimensions of Energy Security and Emerging Challenges—

Summary

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Global Energy Supply and Demand Outlook to 2050

Hormuz closure advances renewables and nuclear; fossil fuels remain dominant

1. We examine global energy supply and demand through 2050 under two scenarios. Under the Reference scenario, which assumes prevailing policy and technology trends, primary energy consumption rises mainly in emerging and developing economies and reaches 12% above its 2024 level by 2050.
2. Under the Advanced Technology scenario, which strengthens energy-security and climate measures and maximizes technology deployment, consumption peaks around 2030 and falls to 7% below its 2024 level by 2050.
3. The outlook incorporates policy and corporate responses to the closure of the Strait of Hormuz, with coal revised upward in the medium term and renewables and nuclear power in the long term. Even so, oil and natural gas remain the largest and second-largest primary energy sources in 2050 under Reference. Both secure fuel supply and the energy transition are therefore essential.

Electrification cuts fossil-fuel dependence; 35% by 2035 remains challenging

4. Electricity's share of global final energy consumption (excluding non-energy use) rises from 24% in 2024 to 35% under Reference and 47% under Advanced Technology by 2050. Electrification is a powerful means of reducing fossil-fuel consumption and import dependence, but the share rose by only five percentage points from 2010 to 2024; replacing equipment and expanding electricity supply take time.
5. Many countries and regions do not reach the 35% electrification target by 2035 even under Advanced Technology. The difficulty and value of electrification also vary: the United Kingdom has a cool climate and a service-oriented economy; Japan has relatively low transport energy consumption; and China has a substantial industrial sector.
6. By 2050, global electricity generation rises to 1.6 times its 2024 level under Reference and 1.8 times under Advanced Technology. In addition to data centers, growth in manufacturing, especially in emerging economies, and rising heating and cooling demand are major drivers. Renewables lead

the increase, while nuclear power expands as a stable low-carbon source. Under Reference, thermal generation remains near its 2024 level and, together with batteries, balances variable renewable output.

Fossil-fuel demand persists; responses must be tailored by fuel and end use

7. **Oil**: Under Reference, global primary oil consumption remains around 99.1 million barrels per day in both 2024 and 2050; under Advanced Technology, it falls to about 60% of today's level by 2050. Road transport has substantial reduction potential, but EV adoption depends on subsidy policies, and high vehicle prices may constrain uptake, especially in emerging economies. Non-energy use in chemicals is harder to replace. As demand in developed Asian economies and China shifts from road transport toward feedstock for chemicals and other transport (aviation, maritime), refineries must adapt to higher shares of naphtha and middle distillates; petroleum-product trades with other countries also worth consideration.
8. **Natural gas**: Under Reference, global primary consumption rises about 21%, from 4.26 trillion m^3 in 2024 to 5.16 trillion m^3 in 2050, with growth in power, industry, and residential and commercial use. Even under Advanced Technology, it declines less than oil. Gas balances variable renewables in power generation and high-temperature industrial heat is hard to replace, therefore requiring supply security measures including diversification of import partner.
9. **Coal**: Consumption declines in both scenarios, but remains above 3,000 Mtoe (million tonnes of oil equivalent) in 2050 under Reference. A reassessment of energy security following the Strait of Hormuz closure has led to an upward revision from last year's outlook. Most potential reductions are in power generation; while reductions in steelmaking are limited.

Asia's energy security: China's curtailment and Indonesia's oil-supply challenges

10. **China**: Primary energy consumption begins falling around 2030. Renewables and EVs lift overall energy self-sufficiency to 93% by 2050 under Advanced Technology. Yet renewable curtailment has risen annually, reaching 9% of generation in the first half of 2026. As capacity will grow further, mitigating curtailment remains a key energy-transition challenge.
11. **Indonesia**: Overall energy self-sufficiency exceeds 100%, but oil self-sufficiency was only 42% in 2024, reflecting inadequate crude output and refining capacity. Electrification can curb oil dependence addressing growing energy demand, Indonesia have to expand power supply capacity in parallel. Efficiency gains, biofuels, diversified procurement, and petroleum-product trades with other countries must together support secure supply.

Fossil Fuel Security – focusing on Asia

The role of fossil fuels and supply risks for Asia

1. Fossil fuels are essential to economic and social activity, as fuels for transport, power generation, industry and buildings, and as feedstocks for steelmaking and chemicals. Excluding China, which has a relatively high energy self-sufficiency rate, Asia accounted for 18% of global fossil fuel demand in 2024, while fossil fuels represented a high 78% of its energy supply.
2. Asia relies heavily on fossil fuel imports because regional production is insufficient, and supplies to Asia are concentrated in a limited number of countries and regions. Supply disruptions in the Middle East remain a major risk, but numerous other risks exist at every stage of the supply chain. As demonstrated by the closure of the Strait of Hormuz in 2026, large and prolonged disruptions from major sources put pressure on the economic and social activities of Asian importers by tightening the overall supply-demand balance and higher import prices.

Improving fossil fuel supply security in Asia

3. The closure of the Strait of Hormuz has increased the importance of crude oil pipelines that bypass the strait. Numerous pipeline expansion and construction projects are planned in the Middle East, including the expansion of the UAE's Habshan–Fujairah crude oil pipeline. These projects need to be realized promptly, although the risk of supply disruption caused by attacks on pipelines will remain. There is also no clear prospect of measures to reduce the dependence of oil products and natural gas on the Strait of Hormuz.
4. Given the high concentration of supplies to Asia, fossil fuel supply sources need to be diversified. It is desirable to purchase a certain volume from alternative suppliers under term contracts even in normal times, but doing so often increases transport distances and procurement costs. The extent of procurement from alternative sources and the allocation of additional costs therefore need to be considered together.
5. Stable investment is essential to improve fossil fuel supply security. In particular, upstream oil and gas investment, which accounts for the bulk of fossil fuel investment, needs to be secured. Long-term contracts with new LNG projects also remain important in supporting investment. Although investment in coal is smaller than investment in oil and gas, maintaining existing coal mines particularly in Australia, along with export infrastructure such as railways and ports, is essential.
6. Reducing demand through energy efficiency and fuel switching is another effective way to secure stable fossil fuel supplies. In the Advanced Technologies Scenario, Asia's fossil fuel demand in 2050 could be 30–50% lower than in the Reference Scenario. Transport electrification contributes particularly to reducing oil demand, industrial energy efficiency to reducing natural gas demand,

and a shift towards renewable power generation to reducing coal demand.

7. Southeast and South Asia, which were heavily affected by the closure of the Strait of Hormuz, have low oil stock levels and insufficient refining capacity. Given their high dependence on the Middle East and expected demand growth, importers in these regions need to expand oil stockpiles and refining capacity in cooperation with Middle East crude exporters and other partners.
8. Diversifying supply sources increases transport distances and the shipping capacity required. It is therefore desirable to secure a certain level of shipping capacity in normal times when developing alternative sources. Shipments from alternative sources to Northeast Asia and some Southeast Asian countries will often pass through the Strait of Malacca and South China Sea. To prepare for disruptions to navigation in these waters, the necessary navigation infrastructure should be developed along alternative routes through, for instance, the Lombok and Makassar straits.
9. Diversification can be supported by procuring a certain volume under term contracts in normal times, alongside spot purchases. However, CIF and DES contracts, under which sellers arrange transport, may restrict contractual destinations and limit resale to third countries or cargo redirection in response to supply and demand conditions. To improve emergency response capacity and supply security, Asian importers should seek greater market liquidity through increased supplies of destination-flexible LNG from the United States and other sources.

Electricity Security Challenges Posed by the Growth of Data Centers

1. Driven by the widespread adoption of generative AI and ongoing digitalization, data center development is accelerating worldwide. According to the International Energy Agency's World Energy Outlook 2025, global electricity consumption by data centers is projected to increase from approximately 400 TWh in 2024 to around 950 TWh by 2030. In the United States in particular, data centers are expected to account for approximately half of the increase in electricity demand through 2030, raising concerns about their impact on the reliability of electricity supply.
2. Growing electricity demand from data centers could have significant impacts on power systems due to the scale, geographic concentration, and pace of development. In recent years, some projects have required several hundred MW to GW-scale electricity supply at a single facility. Data centers also tend to concentrate in specific regions, reflecting factors such as access to telecommunications infrastructure and electricity supply conditions. Furthermore, there is a significant mismatch between the pace of data center development and the lead times required to develop new generation and transmission infrastructure. Future demand is also uncertain due to grid connection applications at multiple locations, project delays, and cancellations. These characteristics raise important questions about when the necessary infrastructure should be developed and who should bear the associated investment costs.
3. The rapid growth of data centers raises three fundamental challenges for electricity security. The first is whether sufficient generation capacity can be secured. In the PJM region of the United States,

capacity market prices have risen sharply due to growing electricity demand, particularly from data centers, and the retirement of existing power plants. However, higher capacity prices do not necessarily lead to the rapid development of new generation capacity, as power plant construction requires considerable time for permitting, equipment procurement, and grid connections. Therefore, a key challenge is to maintain existing generation capacity, promote investment in new power plants, and ensure that large electricity loads and the generation capacity needed to serve them are secured in a coordinated manner.

4. The second challenge is whether electricity can be reliably delivered to the locations where it is needed. Even if sufficient generation capacity is available across the power system, inadequate transmission capacity in areas where data centers are concentrated may prevent new loads from being connected. In PJM, efforts are underway to optimize existing transmission infrastructure and reinforce backbone transmission networks in anticipation of future demand growth. Measures are also being considered to enable earlier grid connections before reinforcement is completed by requiring a certain degree of demand-side flexibility, including restrictions on electricity consumption.
5. The third challenge is whether the necessary investments can be made under sustainable cost allocation arrangements. If infrastructure is developed in anticipation of future demand but projects are subsequently modified or canceled, investment costs may not be fully recovered, potentially shifting the financial burden to other electricity consumers. In response, U.S. utilities are increasingly requiring large electricity consumers to make financial commitments through long-term contracts, minimum charges, and financial security requirements. It is therefore important to verify the feasibility of demand projections and establish mechanisms to ensure that costs arising from project modifications or cancellations are appropriately allocated.
6. These challenges related to generation capacity, transmission capacity, and cost allocation are also affecting local community acceptance of new data center developments. In the United States, opposition from local residents is growing due to concerns over electricity and water consumption, higher electricity bills, and impacts on living conditions. In response, some state and local governments have begun introducing restrictions on new data center developments.
7. Japan is also implementing measures to address geographically concentrated growth in large-scale electricity demand, including preventing speculative grid capacity reservations, improving cost allocation, and promoting proactive grid development in anticipation of future demand. U.S. experience highlights the importance of verifying the feasibility of large-load projects and reflecting their likelihood of realization in electricity demand forecasts and grid planning. It also suggests the value of establishing integrated grid connection studies that jointly assess large electricity loads and generation facilities.
8. Data centers are essential infrastructure supporting AI and digitalization. Rather than uniformly restricting their expansion, the challenge going forward is to establish regulatory and institutional frameworks that enable large new electricity loads to be connected as quickly as possible while

ensuring reliable electricity supply and appropriate cost allocation.

Security Challenges Associated with the Expansion of Renewable Power Generation

Industrial Competition in Decarbonisation Technologies

1. Since the 2000s, emerging economies, particularly China, have significantly increased their share of global manufacturing value added. Industries associated with decarbonisation technologies, including solar photovoltaics (PV), have also expanded rapidly. China, in particular, has established strong competitiveness in these industries, supported by the expansion of production capacity and technological advancements.
2. Countries are increasingly introducing policies to promote decarbonisation technologies as a key pillar of industrial competitiveness. Industrial competitiveness policies announced by China, the European Union (EU) and South Korea in 2026 emphasise the promotion of renewable energy, hydrogen and ammonia, as well as the strengthening of domestic and regional industrial bases. In Japan, policies related to Green Transformation (GX) are also translating into concrete initiatives to accelerate the commercial deployment of decarbonisation technologies.

Concentration of Manufacturing Capacity and Diversification of Supply Chains

3. Global manufacturing capacity for renewable energy technologies, including solar PV and wind power equipment, is currently highly concentrated in China. While this concentration raises concerns about market dominance and supply chain dependence, importing countries, including Japan, also benefit from access to low-cost equipment of sufficient quality.
4. The concentration of manufacturing capacity has prompted efforts to restructure and diversify supply chains. China is pursuing domestic industrial restructuring while maintaining its production capacity, whereas India is promoting domestic manufacturing through its Make in India initiative. ASEAN is strengthening its position as an alternative manufacturing and export hub. Meanwhile, the United States is making use of tariffs and regulatory measures, while Europe is seeking to strengthen domestic manufacturing capacity under the Net-Zero Industry Act.

Contribution of Resource Circularity to Resource and Economic Security

5. The continued expansion of renewable power generation capacity will increase the importance of

securing critical minerals and managing the large volumes of equipment expected to reach the end of their operational lives in the future. Recycling renewable energy equipment is becoming not only an environmental measure but also an integral component of resource and economic security policies.

6. Major economies are developing regulatory and policy frameworks to promote resource circularity, including the EU's product passport system, China's guidelines on circular resource utilisation, recycling support measures in the United States, and India's e-waste management policies. Looking ahead, collection networks, international standards and product traceability systems will need to be developed alongside measures to promote the use of recycled materials. Together, these efforts will be essential to stimulate demand for recycled materials and establish circular supply chains for renewable energy equipment.

Electrification and Emerging Cybersecurity Risks

7. Amid growing concerns over cybersecurity, the number of cyberattacks causing substantial financial losses has increased significantly since the mid-2010s. One notable example is the 2015 cyberattack on electricity distribution companies in Ukraine, which disrupted electricity supply to approximately 225,000 customers. Restoration took three to six hours.
8. As electrification progresses and electricity accounts for an increasing share of final energy consumption, addressing cyber threats to electricity-related equipment will become increasingly important. In particular, cybersecurity risks associated with small-scale distributed energy resources (DERs), such as rooftop solar PV systems and battery storage, represent an emerging challenge. Cybersecurity measures must therefore extend beyond individual power plants to encompass the entire power system, including distributed energy resources.
9. Power conditioning systems (PCSs) used in solar PV installations, as well as inverters widely deployed in battery storage systems and household appliances, may be vulnerable to unauthorised access and remote manipulation through communication functions and cloud connectivity. Furthermore, as with solar PV modules and battery cells, global inverter manufacturing capacity is concentrated in a limited number of countries. This concentration could expose power systems to overlapping risks arising from supply chain dependence and cybersecurity vulnerabilities.
10. As part of its response, Japan has indicated its intention to require certification under a cybersecurity labelling scheme for distributed energy equipment, including solar PV systems. In ASEAN, efforts are underway to assess cybersecurity vulnerabilities in DERs and discuss common security standards. The United States, the EU, Lithuania and Germany are also implementing measures such as imposing procurement restrictions, establishing mechanisms to disconnect potentially vulnerable equipment from the grid, and strengthening safeguards against unauthorised remote control.

Increasingly Interconnected Security Challenges in Renewable Power Generation

11. The expansion of renewable power generation is giving rise to increasingly complex and interconnected security challenges involving industrial competitiveness, supply chain resilience, access to critical minerals and cybersecurity. These issues can no longer be addressed independently and require a more integrated approach to energy and economic security.
12. Policy responses need to be tailored to renewable energy technologies and equipment, taking into account their technological characteristics, industrial competitiveness and sensitivity from a security perspective. In industries where economies of scale are a major determinant of competitiveness, cross-border alliances may offer an effective means of securing production capacity and cost competitiveness. Conversely, for technologies and equipment that are more sensitive from a security perspective, it may be necessary to establish national or regional supply chains and governance frameworks to ensure adequate security and oversight.

Security of Critical Minerals

Growing Importance of Critical Mineral Security

1. While the deployment of clean energy technologies reduces the risk of disruptions to fossil fuel supplies, it requires large quantities of critical minerals such as copper, lithium, nickel, cobalt, graphite, and rare earth elements. Production and refining of these minerals are concentrated in a small number of countries and are vulnerable to geopolitical factors, meaning that reduction of fossil fuel supply risks creates another security risks of critical mineral supply.

Risk Assessment of Critical Minerals

2. Each critical mineral has its own risks. These risks were assessed from four perspectives: (1) resource size (years of reserves remaining), (2) supply concentration (Herfindahl-Hirschman Index: HHI), (3) political stability of supplier countries (World Bank's World Development Indicators), and (4) supply-demand balance (supply-demand gap ratio in 2040).
    - Resource size: The remaining years of reserves are relatively low for nickel (36 years), cobalt (37 years), and copper (49 years). While the figure for rare earth elements as a whole is high at 193 years, it falls to 78 years for heavy rare earth elements.
    - Supply concentration: Graphite and rare earth elements show high concentration particularly in their refining sectors. The HHI for heavy rare earth refining is 9,606, indicating an almost complete Chinese monopoly. Overall, concentration is higher at the refining stage than at the

production stage.

- Political stability: Except for cobalt production, there are no major differences in risk levels among the minerals. However, the risks of dependence on countries that use exports as a tool of economic coercion should be considered higher than the indicators suggest.
- Supply and demand balance: All the minerals are projected to face excess demand in 2040. This does not necessarily mean that actual supply shortages will occur; rather, it should be interpreted as indicating the need for investment in future supply.

3. Overall, no critical mineral can be considered low in importance and therefore low in risk. Measures to secure supply must be tailored to the specific risks of each mineral.

Supply Chain of Rare Earth Elements and Neodymium Magnets

4. More than 70% of the market value of rare earth elements is associated with magnets. Neodymium magnets are widely used in automobiles, wind power generation, data centers, robotics, and defense equipment, potentially creating competition among these sectors for supply. China accounts for about 60% of mined ore production, but its share rises to around 90% in separation and refining and over 80% in magnet manufacturing. Thus, diversifying upstream sources does not eliminate concentration in the midstream and finished-product stages. Japan's imports of rare earths and magnets from China declined during the 2010s but are returning to around their 2010 levels, partly as Japanese companies expanded their magnet manufacturing capacities in China. China's export controls, strengthened from 2025, also cover products such as magnets, making it essential to address risks across the entire supply chain.

Measures Going Forward

5. Because critical mineral security is closely linked to future energy supply and demand, an integrated approach is needed to ensure the security of both energy and critical minerals. Potential measures include: (1) developing integrated supply-demand outlooks; (2) improving energy and resource efficiency; (3) securing a diverse range of technology options (including pumped-storage hydropower, PHEVs, FCVs, CCS, and hydrogen); (4) expanding stockpiling capacity; (5) international cooperation with Asia under the framework of POWERR Asia; and (6) promoting recycling.
6. To date, governments have played the leading role in measures to secure stable supplies of critical minerals. However, companies also need to act to respond flexibly when supply disruptions occur. The automotive industry is already pursuing upstream investment in mining sector, midstream investment in magnet factories, private stockpiling, alternative technologies (such as rare-earth-free magnets and magnet-free motors), and recycling. How these efforts are combined with

government policies will be an important challenge going forward.

Comparison with the Previous Year's IEEJ Outlook

Updates to Historical Data and Projections

Historical economic and energy supply and demand data were updated by one year, and changes in political conditions and climate change policies were also taken into account. As a result, historical data and projections under the Reference Scenario were updated as follows compared with the previous year's IEEJ Outlook 2026. It should be noted that retrospective revisions to historical data have resulted in upward revisions to energy demand, particularly in recent years, compared with the projections in IEEJ Outlook 2026.

Impact of the Closure of the Strait of Hormuz on the Projections

In IEEJ Outlook 2027, coal consumption was revised upward based on the assumption that the closure of the Strait of Hormuz in February 2026 would heighten supply risks associated with natural gas from the Middle East, leading to a reassessment of the role of coal-fired power generation over the medium to long term. Accordingly, the projections incorporated the possibility of higher capacity factor and new construction of coal-fired power plants in the United States, China, and ASEAN countries.
Natural gas consumption was revised downward over the medium to long term, particularly in natural gas-importing countries, including Vietnam, Thailand, and other Asian countries such as Indonesia, where domestic natural gas demand is projected to exceed production around 2030, based on the assumption that the closure of the Strait of Hormuz would heighten concerns over supply risks. Nuclear power generation was revised upward from 2030 onward, primarily in North America and China, reflecting the latest national plans and targets. Renewable energy generation, including solar photovoltaics and wind, was revised upward based on the assumption that the oil and natural gas crisis resulting from the closure of the Strait of Hormuz would accelerate the long-term energy transition and the deployment of solar photovoltaics. However, by more accurately accounting for recent patterns in renewable energy curtailment in this year's analysis, electricity generation per unit of installed capacity was revised downward in some countries and regions, despite an increase in global installed capacity.

Overview of Global Energy Supply and Demand Projections

Global primary energy supply in 2024 increased by 244 Mtoe, or 1.6%, due to updates to historical data,

while the projection for 2050 increased by 113 Mtoe, or 0.7%, compared with IEEJ Outlook 2026.

By energy source, oil consumption in 2024 increased by 0.5% due to updates to historical data. However, heightened concerns over geopolitical risks resulting from the closure of the Strait of Hormuz are expected to accelerate the shift from oil to electricity and biofuels over the medium to long term. Consequently, oil consumption in 2050 was revised downward by 108 Mtoe, or 2.3%. Natural gas consumption in 2024 increased by 2.2% due to updates to historical data. Over the medium to long term, however, the impact of the closure of the Strait of Hormuz is expected to lead to reduced use of natural gas-fired power generation, resulting in a downward revision of 186 Mtoe, or 4.2%, in 2050. Coal consumption in 2024 increased by 2.6% due to updates to historical data. Furthermore, increased reliance on coal-fired power generation over the medium to long term in response to the closure of the Strait of Hormuz resulted in a substantial upward revision of 175 Mtoe, or 5.6%, in 2050. Nuclear energy supply in 2050 was revised upward by 106 Mtoe, or 10.9%, reflecting the latest national plans and targets. Other renewables were revised upward by 99 Mtoe, or 5.7%, in 2050, reflecting an accelerated shift toward biofuels.

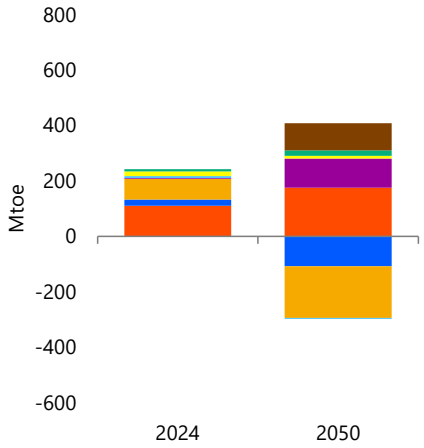
Global electricity generation in 2024 was revised upward by 0.8 PWh (petawatt-hours), or 2.6%, following updates to historical data, while the projection for 2050 increased by 0.6 PWh, or 1.2%, compared with the 2050 projection in IEEJ Outlook 2026. Hereafter, future projections are compared with the corresponding projections in the previous year's IEEJ Outlook 2026.

By power source, the revisions to electricity generation in 2050 were +0.0 PWh for oil, +0.9 PWh for coal, −1.1 PWh for natural gas, +0.4 PWh for nuclear, +0.0 PWh for hydropower, +0.2 PWh for wind, +0.1 PWh for solar photovoltaics, and +0.2 PWh for other renewables.

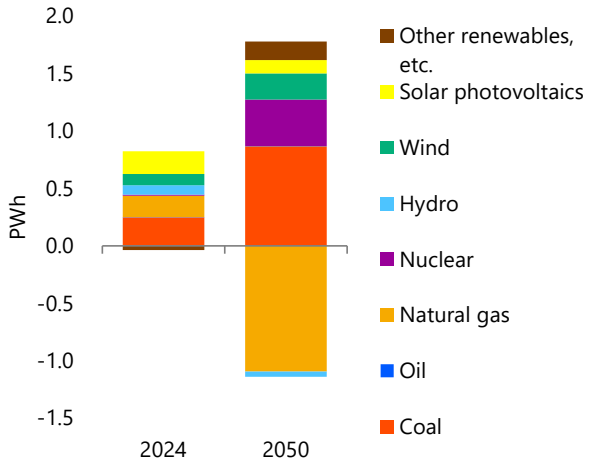
Global CO_2 emissions in 2024 increased by 2.1% due to updates to historical data. For 2050, primary energy consumption per unit of GDP increased compared with the 2050 projection in IEEJ Outlook 2026, partly reflecting a downward revision to the GDP assumptions. In terms of the energy mix, the effects of declining oil consumption and increasing nuclear and renewable energy supply were offset by an increase in coal consumption, leaving CO_2 emissions per unit of primary energy consumption virtually unchanged.

Figure 0-1 | Comparison of Global Primary Energy Supply and Power Generation Mix with the Previous Year's Outlook (IEEJ Outlook 2026) [Reference Scenario]

Primary Energy Supply



Power Generation Mix



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