Climate Change: A drastic change in the natural environment brings out the vulnerability of the power sector

Teruhi Fukano

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EXECUTIVE SUMMARY

Adaptation and mitigation actions are complementary approaches that can jointly reduce the costs and risks associated with climate change and extreme weather. “Mitigation” involves reducing the emissions of greenhouse gases, particularly carbon dioxide (CO_2), which has the greatest impact on global warming. “Adaptation” involves anticipating the adverse effects of climate change and taking appropriate action to prevent or minimize the damage; adaptation measures cultivate the ability to respond flexibly to any change (i.e., to enhance “climate resilience”).

Energy infrastructure, and electric power in particular, are vulnerable to damage from changing climate conditions. The main causes of failure in the electric power system are flooding in hydroelectric facilities, earthquakes in thermal power plants, flooding and earthquakes in substations, lightning strikes on transmission lines, and wind, rain, and thunder along distribution lines. As climate change continues, more frequent, severe, and longer-lasting extreme weather events are most likely to destabilize the power supply. Thus far, power companies in Japan have achieved the world’s most reliable supply of electricity by building disaster-resistant facilities, reducing the impact of disasters, and preparing for quick recoveries. Nevertheless, as global warming continues, “unprecedented” high temperatures, heat waves, droughts, heavy rains, and typhoons are expected to continue increasing in frequency and severity over the coming century. The natural environment surrounding energy systems is expected to change drastically, and this could threaten the stability of Japan’s power supply. Utilities can protect the power infrastructure by undertaking power-specific adaptation measures in parallel with mitigation actions.

The adaptation and mitigation process requires that the power infrastructure be rebuilt, based on reviews of and changes in design and safety standards, and/or that the existing facilities and structures (e.g., the electric grid and power plants) be hardened to align with those standards. Power outages cause cascading impacts on other critical sectors, including transportation and communications, and this could affect economic security. In addition, serious damage to medical facilities could cause human fatalities. In other words, climate resilience measures may have significant co-benefits for economic and human welfare, and this provides an immediate justification for up-front investments in improved infrastructure.

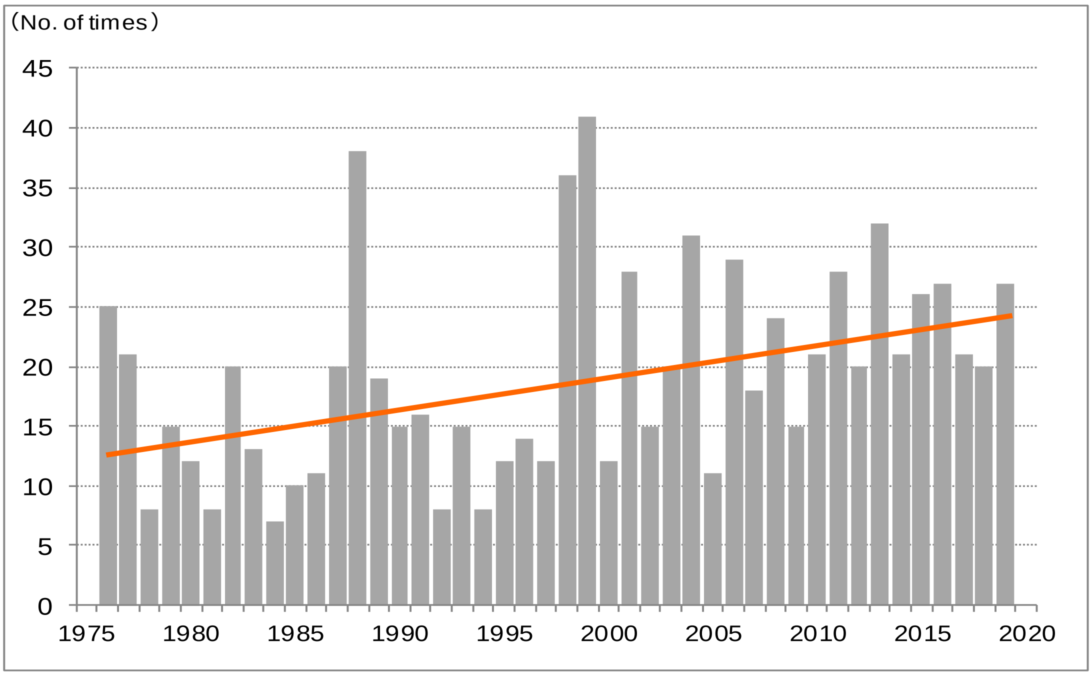
This report summarizes the specific risks that various climate-related natural disasters pose to the power infrastructure, including each fuel source, and it describes the roles of mitigation and adaptation measures to prevent damages.

CHAPTER 1: Risks Posed By Extreme Weather Events

1. Changes in Precipitation Patterns and Flood Risks

The increasing intensity and frequency of typhoons, heavy rains, and extreme rainfall will hurt the nation's economic security. Climate change is also expected to change precipitation patterns significantly. Already, in the past four decades, the frequency of heavy rainfall (defined as 80mm or more per hour) has increased (**Figure 1**). This has produced remarkable damage costs from flood events, including tsunamis (**Figure 2**). The power utility and transportation sectors are especially vulnerable to flooding, and their damages account for 80% of the costs of these damages in the public section (**Figure 3**).

Figure 1 **Annual incidence of heavy rainfall (> 80 mm in one hour) in Japan (1976–2019)**



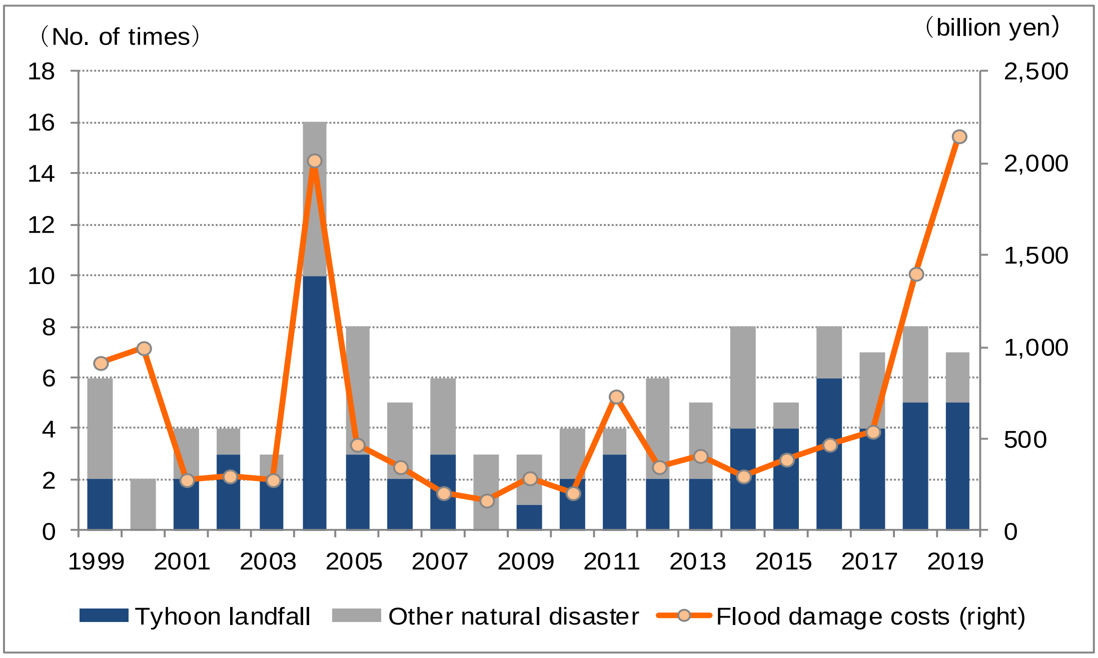
Source: Japan Meteorological Agency (JMA)

Note: Annual incidence per 1,300 sites

The straight line shows a long-term trend (i.e., the average change over this period).

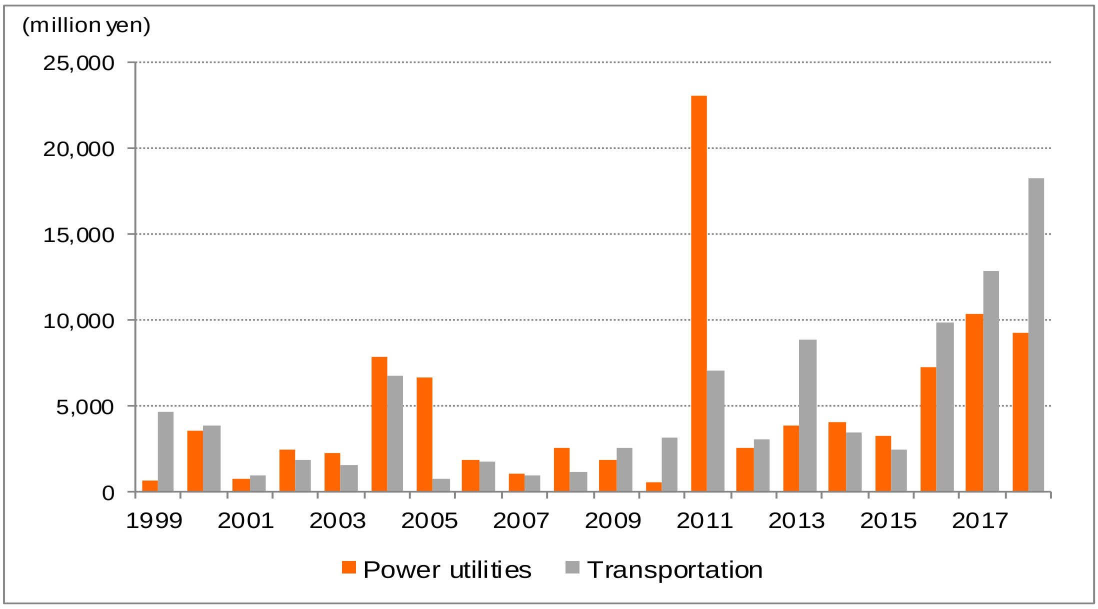
Rainfall of more than 80 mm in one hour warrants heavy caution as there is a high risk of large-scale disasters caused by the rain.

Figure 2 Climate events and flood damage costs



Source: JMA[7] and Ministry of Land, Infrastructure and Transport (MLIT)[8]

Figure 3 Flood damage to public sector



Source: MLIT "Flood Damage Statistics"

7 気象庁 「災害をもたらした気象事例」, 「平成 31 年・令和元年(2019 年)全国災害時気象概況」, March 2020. See https://www.data.jma.go.jp/obd/stats/data/bosai/report/index_1989.html (as of 2020/7)
8 MLIT , "Flood Damage Statistics" . See https://www.mlit.go.jp/river/toukei_chousa/kasen/suigaitoukei/index.html (as of 2020/7)

Table 1 Inundations and damages to thermal power plants hit by the 2011 East Japan Earthquake and Tsunami

Power Company	Name of Power Plant	Generation Capacity [10,000 kW]	Types of fuel	Depth of floodwaters [GL+m]*	No. of units per plant (Suspended & Damaged unit / Total units)	Days to suspend plant operations: First unit	Days to suspend plant operations: All units
Tohoku Electric	Haramachi	200	Coal	13	2/2	749	777
Tohoku Electric	Sendai	44.6	LNG	4.7	1/1	334	0
Tohoku Electric	Shin-Sendai	95	Oil	3	2/2	291	shut down
Soma Kyodo	Shinchi	200	Coal	3	2/2	283	291
Joban Joint	Nakoso	162.5	Oil &Coal	1.8	4/4	111	407
TEPCO	Hitachinaka	114	Coal	1.5	1/1	65	0
Kashima Kyodo	Kashima Kyodo	105	Oil	NA	3/3	36	131
TEPCO	Kashima	440	Oil	1	6/6	21	66
TEPCO	Higashi Ogishim	200	LNG	NA	1/2	13	0
Tohoku Electric	Hachinohe	25	Oil	0.5	1/1	9	0
TEPCO	Ohi	105	Oil	NA	2/3	2	6
Tohoku Electric	Noshiro	120	Coal	NA	2/2	2	3
Tohoku Electric	Akita	130	Oil	NA	3/3	1	1
J Power	Isogo	120	Coal	NA	1/2	1	0
Sakata Kyodo	Sakata Kyodo	70	Coal	NA	1/2	1	0

Source: Ayumi Yuyama and Yoshio Kajitani, "Estimation of damage and recovery function of thermal power plants based on the data of the 2011 Tohoku Earthquake and Tsunami"

* GL+m=Ground Level + meter(s)

Thermal power and hydropower plants and substations have not taken adequate disaster measures to develop climate resilience. After the Fukushima nuclear accident, power companies strengthened flood countermeasures in anticipation of tsunamis and other disasters, but they did not take necessary measures for power sources other than nuclear power generators. Many of the thermal power plants located on the Pacific coast were damaged by the tsunami of the Great East Japan Earthquake in March 2011. The damaged thermal power plants required at least one week to resume operations, and the most damaged plants remained inactive for more than two years. The greater the depth of inundation, the longer the suspension period (**Table 1**).[9] The heaviest damages were

[9] Ayumi Yuyama and Yoshio Kajitani, Central Research Institute of Electric Power Industry, "Estimation of damage and recovery function of thermal power plants based on the data of the 2011 Tohoku Earthquake and Tsunami", Feb.22, 2014, p. I_666. See https://www.jstage.jst.go.jp/article/jscejseee/70/4/70_I_664/_pdf (as of 2020/8).

sustained by harbors and cargo handling equipment, fuel storage and transportation equipment, and water supply and drainage equipment installed on the seaward side of the site.

2. The Rising Sea Level, Windstorms, High Waves, and Storm Surges

As the oceans absorb heat, ocean temperatures rise and the water expands. This thermal expansion contributes to an increase in the global sea level (GSL). From 1901 to 2010, the global sea level rose an estimated 187 mm. This represents an average annual rise of 1.7 mm,[10] but a disproportionate amount of the increase has occurred in recent years, with an estimated annual rate of 3.2 mm from 1992 to 2010.

The US National Climate Assessment compiled by the National Oceanic and Atmospheric Administration (NOAA) estimated that the GSL will increase by at least 0.2 meters but no more than 2.0 meters by the year 2100.[11] Of course, this is a wide range; the exact rate and its dependence on future greenhouse gas emissions appear uncertain for several reasons. The biggest uncertainty seems to be the future changes in the Greenland and Antarctic ice sheets. It is highly likely that further research by scientists in the US and Europe will estimate a more severe GSL rise than NOAA predicted in 2012. A combination of the GSL rise, storm surges during high tides, and high waves from typhoons and strong winds increase the risk of expanding damage, including the disruption of the power supply, destruction of port facilities, and flooding of coastal energy infrastructure.

3. Higher Temperatures

Japan’s annual power demand has been on a downward trend since peaking in 2007 (**Figure 4**), but the power demand increases between July and September, when the higher temperatures prompt an increase in air conditioning use (**Figure 5**). Rising summer temperatures (associated with the rapid rise in global temperatures overall) are expected to exacerbate this trend. Power companies

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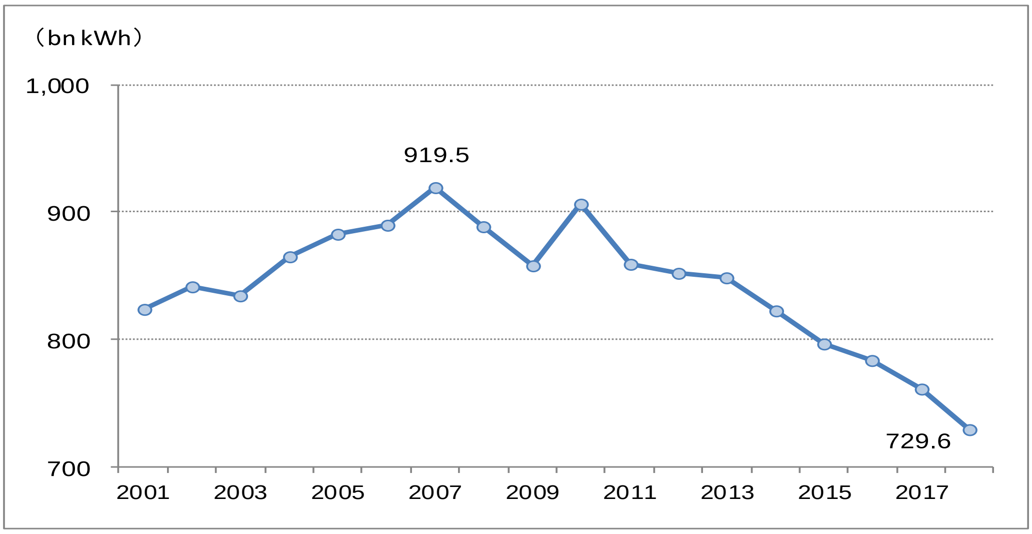
[10] Congressional Research Service, "Sea-Level Rise and U.S. Coasts: Science and Policy Considerations", September 12, 2016, p.12.

[11] Adam Parris et al., NOAA, “Global Sea Level Rise Scenarios for the United States National Climate Assessment”, December 6, 2012, p.1.

should prepare for this change by ensuring adequate generation and storage capacity to meet the highest peak load demand. The power demand is relatively low in the winter except when there is heavy snowfall.

Figure 4 **The rise and fall in Japan's power demand (2001–2018)**



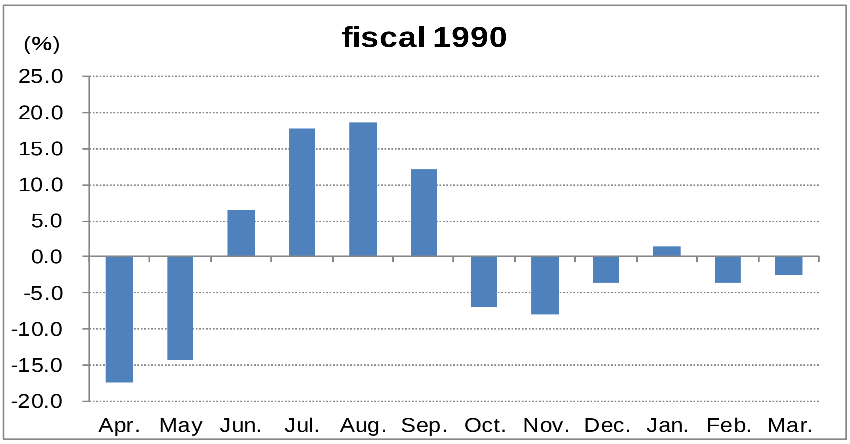
Source: METI and NITE, "Electrical Safety Statistics" [12]

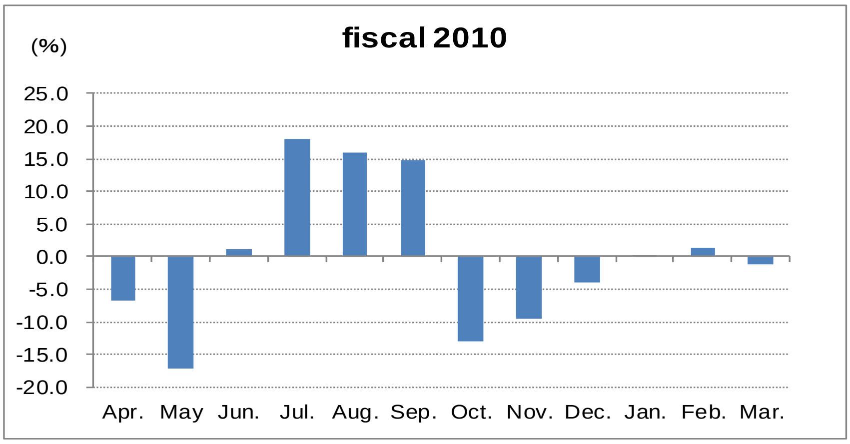
Higher temperatures reduce the efficiency of thermal, nuclear, and solar power generation and could reduce the available generation capacity. In power generators that use oil, natural gas (LNG), or coal, the amount of air taken into the combustor via the air compressor varies depending on the atmospheric temperature; high ambient temperatures reduce the power generation capacity. Specifically, for combined-cycle gas turbines, the supply capacity in the summer is estimated to decrease by 10% to 20% relative to the installed capacity. Similarly, nuclear power generators lose approximately 0.5% of their output capacity per 1 °C increase in the air temperature.[13] Even solar power generators decline in efficiency with extremely high temperatures, as the surface temperature of the solar panel rises.

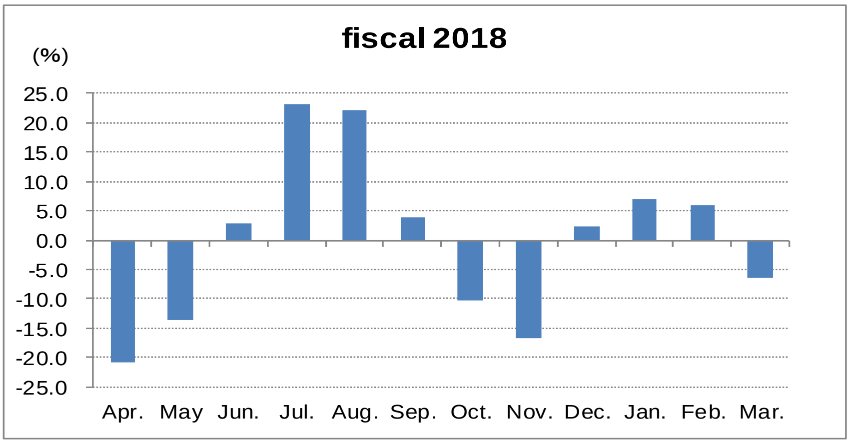
[12] METI and National Institute of Technology and Evaluation (NITE)、「電気保安統計(*Electrical Safety Statistics*)」、p.25　fiscal 2009 and 2018.

[13] DOE, "U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather", July 2013、p.10.

Figure 5 **Seasonal fluctuations in the power demand (from the Tokyo Electric Power Company), shown as a percent difference from the average monthly maximum power**







Source: Based on "Monthly Maximum Power (Maximum per day)" [14] *from TEPCO. The differences were calculated by wonder-news.com.*

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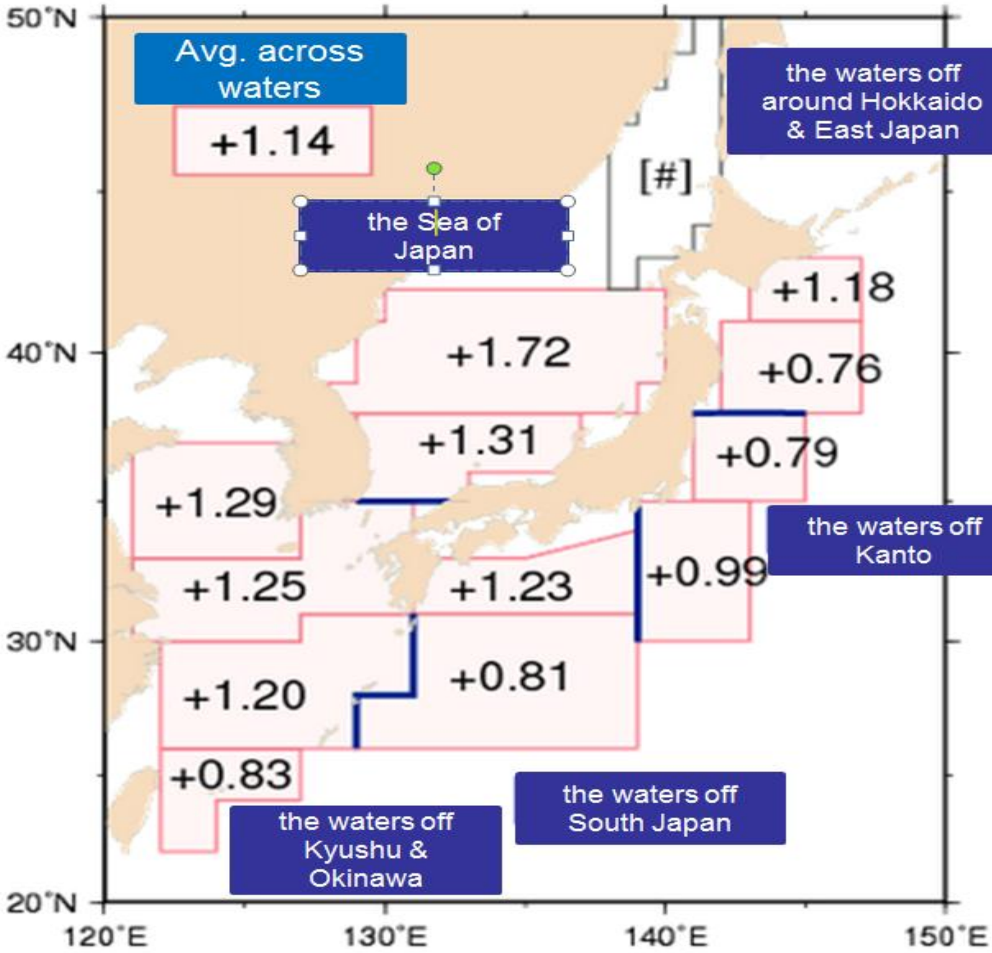
[14] TEPCO, Monthly Maximum Power (Maximum per day)". See https://www.tepco.co.jp/corporateinfo/illustrated/power-demand/peak-demand-monthly-j.html (as of 2020/7).

CHAPTER 2: Risks Associated with Each Type of Power Generation

1. Nuclear Power Generation and Higher Sea Surface Temperatures

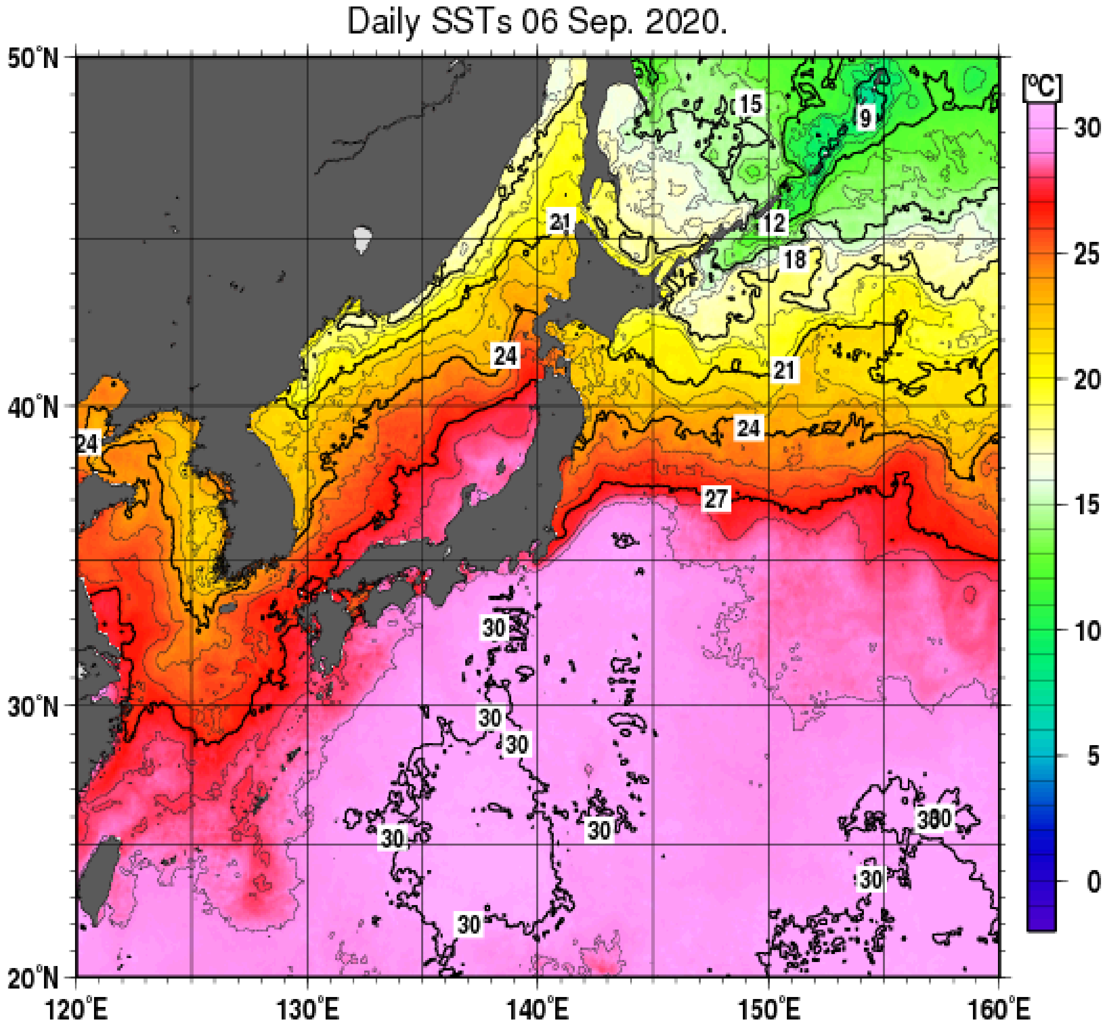
Figure 6 **Long-term changes in the sea surface temperature around Japan, by sea**



Source: JMA Note: # indicates a non-significant long-term trend.

Nuclear reactors are cooled down with fresh coolant water from the sea; a reactor cannot be cooled down completely unless the seawater is sufficiently cold. High sea surface temperatures may reduce the efficiency of the cooling systems of the nuclear power plant. The average sea surface temperature has risen in almost all areas around Japan. As of 2019, the average surface temperature of Japan's seas has increased by approximately 1.14 °C over the past 100 years, representing a more rapid warming than the global average

Figure 7 Current sea surface temperatures around Japan" or "Sea surface temperatures around Japan as of September 6, 2020



Source: JMA

(+0.55 °C in the past 100 years). The sea surface temperature is rising most rapidly in the Sea of Japan and the East China Sea off Kyushu, Kushiro, and Shikoku and Tokai (**Figure 6**).[15] At present, the sea surface temperatures around Japan peak at about 30 °C and remain similarly elevated throughout the summer (**Figure 7**).

There is no formal and standardized threshold for sea surface temperatures

15 Japan Meteorological Agency, 「海面水温の長期変化傾向（日本近海）」, 2019 年. See https://www.data.jma.go.jp/gmd/kaiyou/data/shindan/a_1/japan_warm/japan_warm.html (as of 2020/10)

across the globe. The threshold varies, depending on the reactor types, age, and geographical conditions of nuclear power plants. When the nuclear plants were built 30 or 40 years ago, nobody could imagine sea surface temperatures to exceed 25 °C or more for days or months as it is now.

The magnitude of this risk depends on both the depth of the water used by the nuclear reactor (i.e., deeper water is colder) and the reactor's proximity to other nuclear reactors (because a nuclear reactor's water output is necessarily warmer (+7°C) [16] than the water input). The release of hot water into the sea could be a hazard, depending on the locations of nearby nuclear power plants, the number of reactors and turbines, and other generation equipment that relies on the same source of cool water for safe, efficient power generation. When the seawater is too warm, nuclear power plant operators have to reduce their reactor's power output. This may require unscheduled disruptions in the power output, pushing the price of electricity even higher.

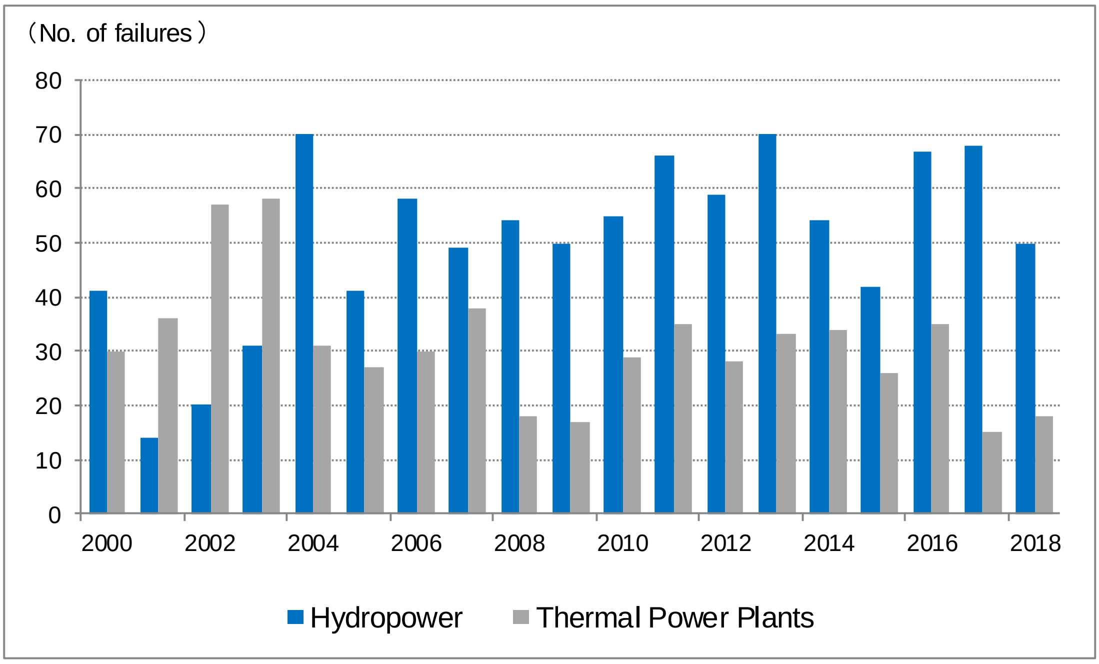
The impending shortage of cool water is a concern for other types of power plants, too (e.g., coal, natural gas, concentrated solar, geothermal). Regardless of the fuel source, the operations are projected to be threatened when water availability decreases or the water temperature increases. Nuclear and coal-fired power plants are especially vulnerable to droughts and heat waves because they rely on the largest volume of water by far. Options for reducing the power sector's vulnerability include 1) switching the fuel source from nuclear and coal to gas, solar, or wind; 2) replacing the water cooling systems with recirculating or dry cooling systems; and 3) switching the water source from seawater to waste water.

[16] Japan Atomic Energy Agency (JAEA), "Atomica". See https://atomica.jaea.go.jp/data/detail/dat_detail_01-04-03-02.html (as of 2020/11)

2. Hydroelectric Power Generation

Future climate conditions will stress energy production infrastructure in all regions—particularly those with the most water-intensive generation portfolios. Hydroelectric power generation has more failures each year than any other power source (**Figure 8**). Landslides, river flooding, and floods caused by heavy rains can cause significant damage to hydroelectric power plants by flooding the generator, blocking the intake with driftwood, and damaging the dam upstream of the power plant. Restoration may take several months, depending on the extent of the damage.

Figure 8 **Number of annual plant failures by power source (fiscal years 2000–2018)**



Source: NITE, "Electrical Safety Statistics"

Energy systems are likely to experience the most severe impacts of changing "water availability," while hydroelectric power plants are at risk of damage from floods caused by heavy rain. The hydropower production capacity may also be threatened by a shrinking mountain snowpack, which decreases the amount of groundwater and river water available for hydropower production. The annual snowfall decreased significantly from the early 1980s to the 1990s in Japan, especially along the Sea of Japan. Groundwater resources will continue to be affected by other factors as well, including changes in precipitation patterns and an increase in evaporation rates and droughts. Overall, these impacts are expected to continue to decrease groundwater availability. The water volume should be monitored especially closely in the areas that are most reliant on hydropower (namely, Gifu, Fukushima, and Nagano).

3. Renewable Energy

The efficiency of solar power tends to decrease with high air temperatures (though this depends somewhat on the materials in the panels). In these instances, the panels must be cooled with water, so water shortages in rivers and reservoirs pose a risk for inland solar power plants. The efficiency of wind power generation varies greatly throughout the year depending on factors such as the wind speed, wind direction, and maximum instantaneous wind speed.

CHAPTER 3: Risks to Substations and Power Grids

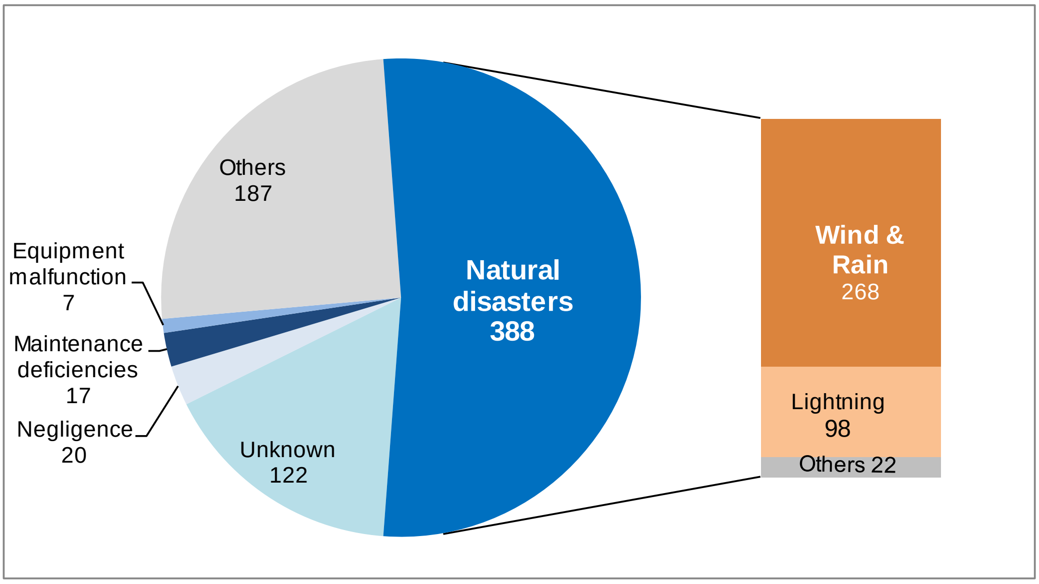
In Japan, the most common causes of electric grid failures are natural disasters: rain and wind (70% of failures), followed by lightning (25%; **Figure 9**). Overhead transmission line failures are more common in years with more extreme weather and other major natural disasters. Distribution lines that send electricity to residential areas are most susceptible to damage from weather disasters, and the failure rate is on the rise (**Figure 10**).

The government has a concern that power outages due to natural disasters may become increasingly prolonged. The maximum wind speed and maximum momentary wind speed both surpassed previous records. Increased wind speeds and precipitation have been correlated with the frequency and duration of power outages, and this damages civilians' confidence in the nation's power system. Specifically, power outages may be caused by the collapse of transmission towers, damage to utility poles from fallen trees or objects swept up in the wind, and the disconnection of distribution lines. A collapsed transmission tower may be bypassed with another tower, but the power failure still tends to be prolonged because it takes time to restore the substation[17] from inundation and the disconnection of overhead transmission lines. Damage to a series of transmission lines increases the cost of restoration considerably, which could push power prices even higher.

Increasing temperatures could reduce the transmission capacity, especially if temperatures remain high at night such that the lines cannot cool effectively (**Figures 11 and 12**). The extent to which heat waves will further reduce both the transmission system's efficiency and available capacity will depend on associated weather conditions (e.g., wind speed, wind direction, temperature, solar radiation). In the summer, when the demand for electricity surges, even power companies that operate at full capacity may be unable to fulfill the demand if the heat decreases the efficiency and capacity of power generation.

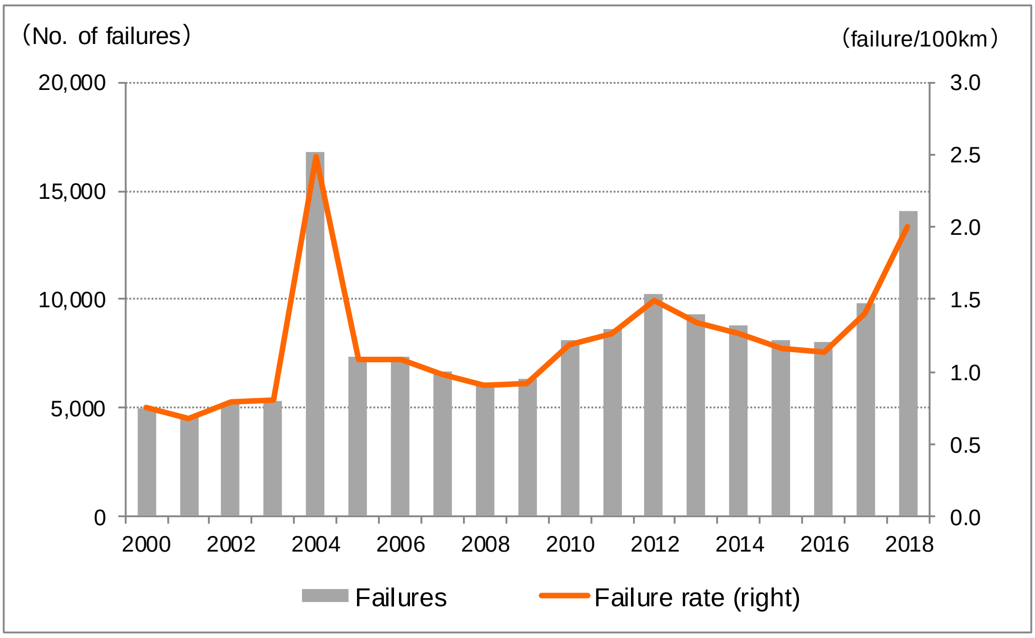
[17] To protect against substation inundation, there are plans to elevate the substation's ground level above the typical depth of rainwater and/or to create nearby "wetlands" (green infrastructure) that can absorb a large amount of water, like a sponge.

Figure 9 Causes of electric grid failures in Japan (fiscal year 2018)



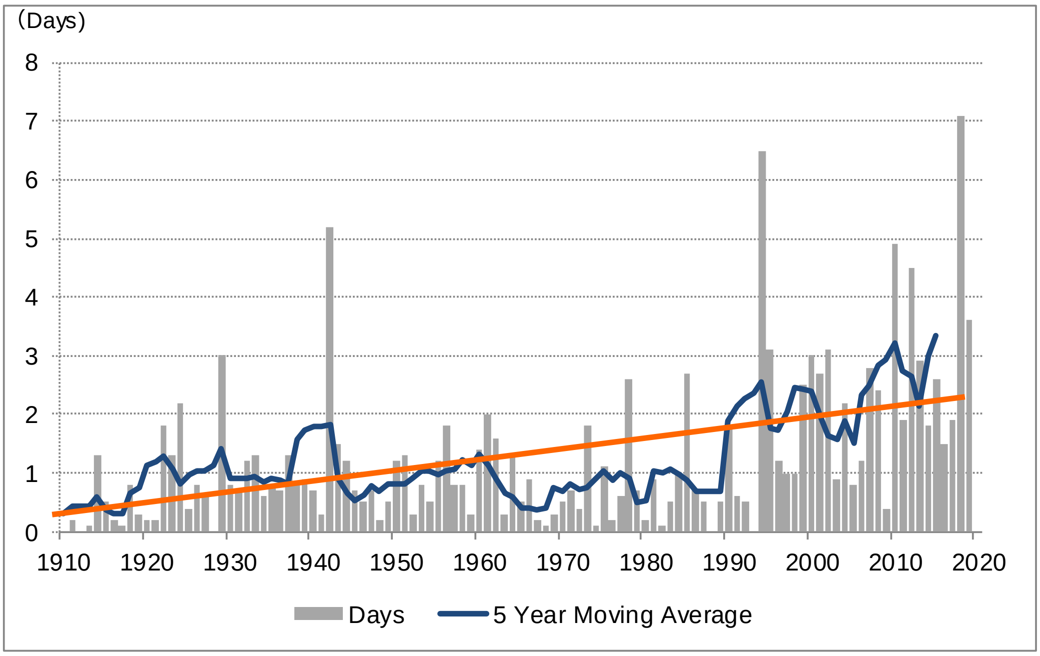
Source: NITE, "Electrical Safety Statistics"

Figure 10 Annual incidence of distribution line failures (fiscal years 2000–2018)



Source: NITE, "Electrical Safety Statistics"

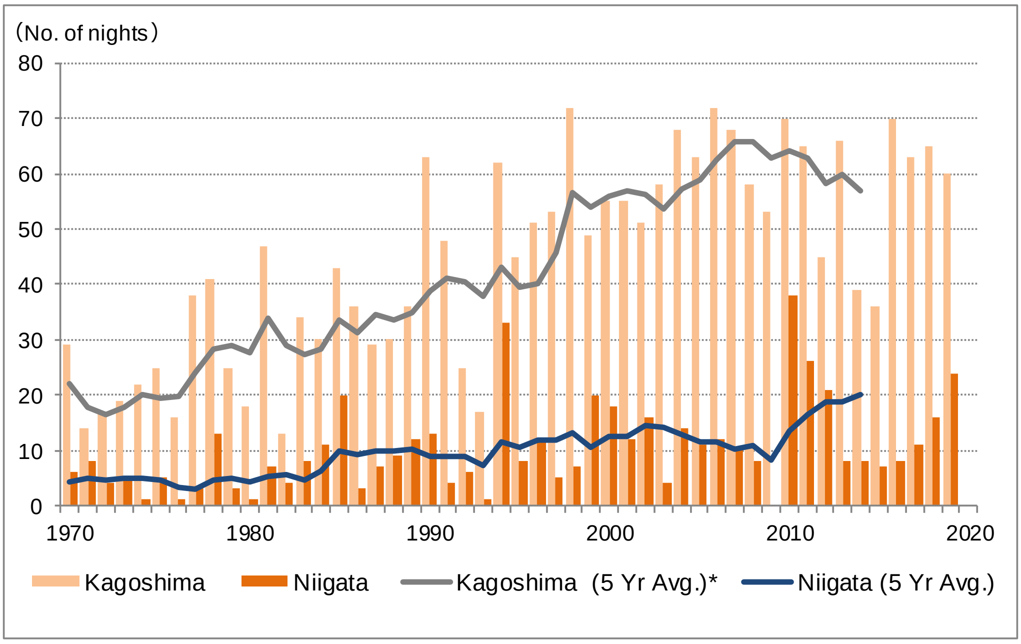
Figure 11 **Number of days per year exceeding 35°C across Japan (1910–2019) ***



Source: JMA

* Average of 13 sites across Japan. The straight line indicates the long-term trend.

Figure 12 **Number of extreme-heat nights (> 25°C) per year in Niigata and Kagoshima (1970–2019)**



Source: JMA

* Line graphs indicate a five-year moving average.

CHAPTER 4: Longer-Lasting Power Outages

The nation's energy system is projected to be increasingly threatened by more frequent and longer-lasting power outages (**Table 2**). In recent years, extreme weather has damaged energy assets in a way that caused widespread, persistent power disruptions in different parts of the country. At present, each ministry and disaster-based (or emergency-prepared) hospital stores enough fuel to generate energy for only three days, but full recovery from a power outage can take weeks. Longer-lasting power outages could result in cascading impacts on critical medical services that are essential for health and safety, other backbone infrastructures, and every sector of Japan's economy. Of all the climate-related adverse events, enduring power outages lead to serious economic fallout.

Table 2 **Impact and duration of power outages in 2018 and 2019, by type of natural disaster**

Date	Type of natural disaster	Damaged electric utility	No. of customers without power at peak (Unit: 1,000 households)	Days to restore power (Days)	
				99%	100%
Jul. 2018	2018 Torrential Rain in western Japan	Chugoku Electric	80	4	7
Sept. 2018	2018 Hokkaido Earthquake	Hokkaido Electric	2,950	2	14
Sept. 2018	Typhoon Jebi (No. 21)	Kansai Electric	2,400	5	14
Sept. 2018	Typhoon Trami (No. 24)	Chubu Electic	1,800	3	7
Sept. 2019	Typhoon No. 15	TEPCO	930	12	16
Oct. 2019	Typhoon No. 19	TEPCO	520	4	5

Source: METI, Agency for Natural Resources and Energy, and TEPCO[18]

99%=99% of power restored.

[18] METI, "The government measures to address massive power outage caused by disasters in 2018", Oct. 18, 2018, *and* "Measure to address natural disasters in fiscal 2018", March 9, 2019, Agency for Natural Resources and Energy, "Japan's first blackout", Nov. 2, 2018, and TEPCO, "The Seventh Power Resilience associated with Typhoon No.15 and measure to restore power", Oct. 3, 2019, p.5, p21. (as of 2020/8)

CHAPTER 5: Adaptation Actions

“Adaptation” involves anticipating the effects of adverse climate-related events and taking appropriate actions to prevent or minimize the anticipated damage. In short, adaptation activities can enhance the preparedness and resilience of the energy system. Adverse events can be assessed by their probability and impact. Scenarios with a lower probability and higher impact may be characterized by thresholds or points beyond which there will be irreversible changes or changes of higher magnitudes than have been experienced previously.[19] All scenarios need to be envisaged and considered, but it is important to recognize that the damage likely will be enormous if climate change progresses beyond the critical threshold. The design and safety standards of the electric power infrastructure should be reviewed under the assumption that such climate change and extreme weather will indeed occur. With this assumption, the electric power infrastructure can be rebuilt according to adaptive principles.

Adaptation measures require an upfront investment in the power system’s future resilience to extreme weather. Some may be tempted to address climate-related damage after it occurs. Climate resilience measures may have significant, near-term benefits that justify an upfront investment (e.g., cost savings through reduced fuel or water usage). It has been shown that well planned, proactive adaptation actions prevent sizable economic and opportunity losses, save lives associated with long-term power outages, and offer enormous synergistic benefits from the upfront investments.

[19] DOE, "U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather", July 2013, p.6.

FUTURE OUTLOOK

Both the US and EU countries have a strong sense of crisis about the impact of climate change on energy security and national security. In the summer of 2020, a record-breaking heat wave sparked an unprecedented series of widespread natural disasters, including wildfires on the west coast of the US and hurricanes that hit and flooded cities in the south. Those who were exposed to such intimidating disasters suffered immeasurable physical and psychological damage. It is no wonder that individuals and nations as a whole are becoming more alarmed that a chain of large-scale natural disasters could threaten national security.

Climate change also poses a serious threat to people's livelihoods, especially for children, the elderly (over 65 years old), and those in the lower income brackets. Global warming has been associated with shortages of essential resources, rising prices of drinking water and food, more frequent allergic reactions, and more frequent outbreak of cholera and other diarrhea illness. Climate change also represents a potentially devastating threat to national power, as discussed extensively in this report. Finally, the threat of climate change and associated extreme weather increases people's uncertainty about the future, potentially causing intense stress that may damage people's mental and physical health.

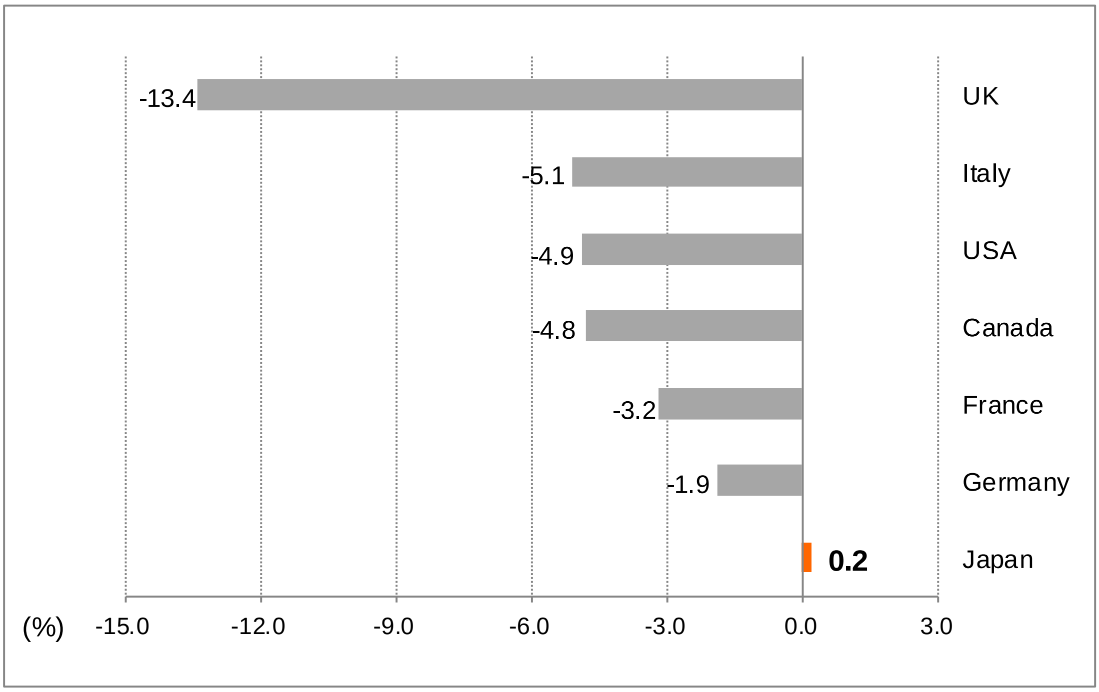
Both the US and EU countries have adopted a scientific perspective to forecast future changes in the global environment and are encouraging gradual changes in industrial structures. In short, these countries are taking proactive measures to address and adapt to climate change.

On the other hand, the Japanese government and companies display little urgency about climate change. Japan's push to build new coal-fired power plants even after the ratification of the Paris Agreement drew condemnation from international anti-coal protesters and green activists (**Figure 13**). In fact, the Ministry of Economy, Trade, and Industry (METI) has maintained its policy of promoting the use of low-grade coal, including "lignite," in steel, hydrogen energy, and coal-fired power generation (IGCC)[20]. Lignite is notorious for being "the

[20] Agency for Natural Resources and Energy, Coal Division in Fuel Dept. "Coal Market Research Report (reference)", 「石炭マーケット研究会報告書（参考資料）」, April 2018, pp. 23, 25.

dirtiest coal" because it emits more carbon dioxide than any other coal. If Japan, the world's third-largest economy, expands its use of lignite, it will face even greater criticism. Although the METI has now announced a commitment to shutting down most coal-fired power plants over the next decade, its recent history of advocating for these same plants makes it difficult to assess whether the METI will be a proponent of or impediment to reducing climate change risks moving forward. We should never forget that neglecting the dangers of natural disasters resulted in the Fukushima nuclear accident. Climate change should not be viewed as merely an environmental issue—rather, all ministries and agencies should view climate change as a pressing threat to each of their domains.

Figure 13 **Coal consumption among the G7 nations**
Annual growth rate (2007–2017)



Source: British Petroleum "BP Statistical Review of World Energy 2019" [21]

Climate change has no borders, and no nation can deal with it alone. It is not an exaggeration to say that there is a global imperative for international collaboration to address and prepare for climate change. Japan's energy system

https://www.meti.go.jp/report/whitepaper/data/pdf/20180430001_1.pdf.

[21] British Petroleum "BP Statistical Review of World Energy 2019", p.45. See https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2019-coal.pdf (as of 2020/8)

already has been affected by extreme weather events that are attributable to climate change. As climate change advances at an alarming rate in the absence of effective mitigation strategies, the need for additional investments in adaptation measures increases. Climate change adaptation and mitigation actions are complementary approaches that jointly reduce the costs and risks of climate change and associated extreme weather events.

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