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RENEWABLE ENERGY INSTITUTE

Verification of Electricity Supply-Demand Balance and Costs in 2030

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Renewable Energy Institute

Renewable Energy Institute is a non-profit think tank which aims to build a sustainable, rich society based on renewable energy. It was established in August 2011, in the aftermath of the Fukushima Daiichi Nuclear Power Plant accident, by its founder Mr. Son Masayoshi, Chairman & CEO of SoftBank Corp., with his own resources.

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Introduction: Background and Objectives

March 11, 2021 marks ten years since the nuclear disaster at TEPCO's Daiichi Nuclear Power Plant. In these ten years, the state of nuclear power has changed significantly. Because of the accident, nuclear power has not only forfeited the trust of the general public but also lost its economic rationality because of the burgeoning cost of safety measures. Its supply capacity is also in decline due to the decommissioning of old reactors. And the prospects are not high for supply capacity in the future.

At the same time, globally, decarbonization is accelerating, with over 120 countries already declaring their commitment to carbon neutrality by 2050. Maintaining these commitments requires increasing energy efficiency and ending adherence to energy systems that depend on fossil fuels. Major countries in Europe and North America have announced plans to phase out coal-fired power and substantially increase deployment of renewable energy by around 2030 (Table 1).

Table 1 Greenhouse Gas Reduction and Renewable Energy Deployment Targets of Major Countries

Country·Area	GHG Reduction Target			Renewable Energy Deployment Targets		Coal phase out
	2050	**2030**	Benchmark year	**2030** (FY2030 for Japan)	2019 actual	Target year
EU	Carbon neutral	▲55%	1990	57% (Final energy consumption is 32%)	35%	–
France	Carbon neutral	▲40%	1990	40%	20%	2022
Germany	Carbon neutral	▲55%	1990	65%	42%	2038
Italy	Carbon neutral	–	–	55%	35%	2025
Spain	Carbon neutral	▲23%	1990	74%	37%	2030
U.K.	Carbon neutral	▲68%	1990	–	36%	2024
U.S.	Carbon neutral	–	–	Zero CO2 emissions from the electric power sector by 2035 (committed) State of California: 60% State of New York : 70%	18%	–
Canada	Carbon neutral	▲30%	2005	–	71%	2030
New Zealand	Carbon neutral	▲30%	2005	100% (Committed)	82%	–
Japan	Carbon neutral	▲26%	FY2013	22～24%	18%	–

Note: The EU's 57% is a published estimate, not a target. In the U.S., one of the campaign promises of President Biden is "to achieve a carbon pollution-free power sector by 2035." In New Zealand, Prime Minister Arden has publicly committed to 100% renewable electricity generation by 2030 (https://www.labour.org.nz/release-renewable-electricity-generation-2030).

Source: Created by REI based on REI, "2030 RE Targets in Europe and U.S." (January 15, 2021); REI, "The Quest to Decarbonize Europe: 2020 Strategies towards 2050" (December 2020); REI, "RE Share in Electricity Consumption 2019" (June 25, 2020); and other documents from the countries' governments.

Even in Japan, Prime Minister Suga, in a policy speech in October 2020, pledged that Japan would reduce greenhouse gas emissions to net zero and achieve carbon neutrality by 2050.

Ahead of this speech, in April 2019, REI released its “Proposal for Energy Strategy Toward a Decarbonized Society,” which puts forth five strategies for achieving net zero emissions by 2050. After that, in August 2020, REI published “Proposal for 2030 Energy Mix in Japan (First Edition),” and explained how it would be possible to achieve a renewable energy share of 45% of total electricity generation by 2030, provided policy measures are taken for this energy transition. Based on this, we proposed a sustainable energy mix for 2030 of 45% renewable energy, zero nuclear power and a phase-out of coal-fired power[1] (Table 2).

Table 2 Sustainable Energy Mix (TWh)

Fiscal Year	FY2010	FY2018	FY2030	Electricity configuration
Electricity demand	1,035	946	850	
Electricity generation	1,149	1,051	890	
Renewables	109	177	400	45%
Nuclear	288	65	0	0%
Coal	320	332	0	0%
Natural gas	334	403	480	54%
Oil etc.	98	74	10	1%

Source: REI (2020), “Proposal for 2030 Energy Mix in Japan (First Edition): Establish a Society Based on Renewable Energy”

In accordance with REI’s policy recommendations, there has been a rapid rise in many Japanese companies and local governments calling for the FY2030 renewable energy target to be raised to 40-50%[2].

A government committee (Advisory Committee for Natural Resources and Energy, Strategic Policy Subcommittee) has been deliberating since summer 2020 on Japan’s energy policy toward

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[1] The definition of coal-fired power phase-out used here relies on the definition provided by Climate Analytics (2019). Which is reducing coal use in electricity without CCS by 90% or more below 2010 levels.

[2] Designated City Council on Renewable Energy, “Proposal on Building a Sustainable Society with Renewable Energy (July 20, 2020)”https://enekyo-city.jp/wp-content/uploads/20200720.pdf
Council on Renewable Energy, “Prescription for Lighting the Future with Renewable Energy” (July 29, 2020) http://www.enekyo.jp/wp-content/uploads/2020/08/20200729.pdfJapan Association of Corporate Executives, “Toward 40% Renewable Energy by 2030: Path to Achievement and Overcoming Barriers” (July 2020)https://www.doyukai.or.jp/policyproposals/uploads/docs/20200729.pdfNational Governors’ Association, “Urgent Proposal for Building a Zero Carbon Society” (August 24, 2020) http://www.nga.gr.jp/ikkrwebBrowse/material/files/group/2/20200824_zc_shiryo01.pdfJapan Climate Initiative (JCI), “92 corporations calling on the Japanese government to raise its 2030 renewable energy target to 40-50%” (January 18, 2021)https://japanclimate.org/news-topics/re2030increment/
https://japanclimate.org/wp/wp-content/uploads/2021/01/JCICompany_RETarget_JP_20210118.pdf

2030 and 2050. In these discussions, some members have supported accelerating the energy transition for decarbonization, but there have also been repeated assertions that the role of renewable energy is limited and an insistence on continued use of nuclear and coal-fired power.

In order to establish a precise strategy for carbon neutrality by 2050, the potential and role of renewable energy, the key to any such strategy, need to be further clarified and a target set for its substantial expansion by 2030[3].

In the "Proposal for 2030 Energy Mix in Japan (First Edition)" released in August 2020, we identified two issues requiring further consideration in connection with the sustainable energy mix: stable supply at all hours, and affordable energy supply. Stable supply at all hours means maintaining power supply to meet demand throughout all 8,760 hours of the year (which also entails maintaining a certain amount of reserve capacity for grid stability). Affordable energy supply means that energy is supplied at prices that the general public and corporations are able to pay. An important part of this is being able to estimate power procurement costs and renewable energy surcharges, which together determine electricity prices. This study considers these two issues in detail.

1 Methods and parameters

1.1 Analysis based on an inter-regional supply-demand model

We first conducted analysis using an inter-regional supply-and-demand model in order to analyze the impact of the sustainable energy mix on supply stability. The model simulates interconnectors between Japan's ten regional service areas. Based on this model, we calculate the supply-and-demand patterns and interconnector currents for each area that will minimize total power costs while upholding the conditions of hourly supply-demand balance for all 8,760 hours (one year) with adequate balancing and reserve capacity.

To build the model, we used PROMOD (made by Hitachi ABB Power Grids), a platform for supply-demand modeling and power market evaluation. With PROMOD, we first created an economical operating plan (unit commitment plan) that meets supply-demand balance and reserve capacity requirements for each area based on data for each power plant, including start-stop times, output change rates, partial load efficiency, and fuel consumption. Then, based on the unit commitment plan, we calculated generation patterns (economic load dispatching) for each plant to minimize total power costs. Based on these results, supply-demand and transmission patterns, curtailments, and short-term marginal costs[4] were calculated for each area.

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[3] REI is planning shortly to publish a roadmap to 100% renewable energy for carbon neutrality by 2050.

[4] Short-term marginal costs are the fuel costs and other variable costs required to raise generating output by, for example, 1 kWh at a power plant. Based on the calculations for economic load dispatching mentioned above, the price at the power plant with the highest marginal costs, among those supplying to each area, was set as the short-term marginal cost price for that area. On the wholesale electricity market's day-ahead market (spot market), bidding takes place based on the short-term marginal costs at each plant, so the short-term marginal cost price, calculated as described above, is one indicator for analyzing the impact on the spot market.

1.2 Main inputs

The main data used to build the model is shown in Table 3. The data is taken from actual area supply-and-demand figures released by general electricity transmission and distribution utilities, interconnector data provided by the Organization for Cross-regional Coordination of Transmission Operators (OCCTO), facility capacity and thermal efficiency figures published by individual power plants, fuel prices based on Japan Ministry of Finance trade statistics, and other sources.

Table 3 Main Inputs

Electricity demand	Area electricity demand data
Nuclear power plants Thermal power plants Geothermal power plants Biomass power plants	Generation capacity, operating period, fuel, partial load efficiency, maximum/minimum output, output change rate for each power plant
Solar power Wind power Hydropower	Area generation capacity, hourly output data
Pumped-storage hydropower	Maximum/minimum generation output, maximum/minimum pumped-storage power, conversion efficiency, reservoir volume
Interconnectors	Interconnector capacity
Fuel prices	Monthly fuel prices for oil, coal, and natural gas
Balancing restrictions	Frequency restrictions, spinning reserve, amount of necessary supply reserve

Source: Created by REI

1.3 Sustainable energy mix evaluation parameters

The sustainable energy mix in this model is based on the following assumptions.

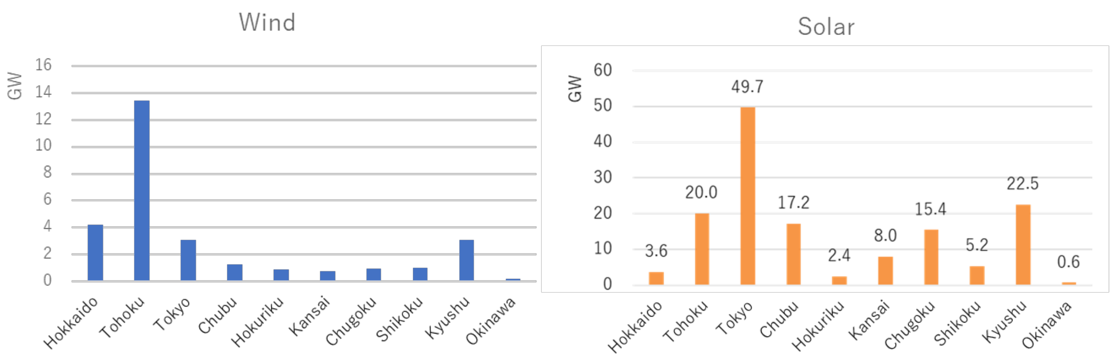
- Grid electricity demand assumed a 7% reduction compared to FY2018 levels based on the sustainable energy mix assumptions in the "Proposal for 2030 Energy Mix in Japan (First Edition)"[5].
- For conventional power source operations, zero nuclear power and zero oil-fired power are

[5] The "Proposal for 2030 Energy Mix in Japan (First Edition)" assumes that electricity demand will decline by 10% from 946 TWh in FY2018 to 850 TWh in FY2030, but this figure includes self-consumption and station service power. Grid electricity demand in this model does not include station service power. Self-consumption power demand is included in grid electricity demand for FY2030 except for consumption of fuel generated secondarily at the power plants.

assumed. The assumption for coal-fired power is that power plants other than ultra-super critical (USC) in regions other than Hokkaido and Okinawa will be shut down by 2030. The model assumes that USC will remain but will be positioned as reserve capacity and that these plants will not generate electricity as long as adequate supply is secured with gas-fired plants alone. In Hokkaido and Okinawa, it was assumed power plants with operating periods of 40 years or less, regardless of fuel, would be able to operate. Natural gas-fired plants with operating periods of less than 60 years were assumed operational.

- Based on industry forecasts, the model expects an increase in Combined Heat and Power (CHP) plants (14.3 GW in FY2030).
- For renewable energy sources, hourly capacity factor for solar power, wind power, and hydropower was set at actual hourly figures from 2018, and capacity factor for biomass and geothermal power uses annual figures. Capacity factor for solar power and wind power in 2030 was set for each region based on the current regional distribution of facility certifications and environmental assessments (Chart 1).
- Fuel prices are taken from IEA World Energy Outlook 2019; they are 9,460 yen/ton for coal, 52,070 yen/ton for LNG, and 60,884 for oil.
- In the model, interconnectors are expected to be enhanced between Tokyo and Chubu and between Tohoku and Tokyo, and planning on them has already been completed.
- Storage batteries of 10.9 GWh are expected to be deployed by FY2030 on a cumulative basis, a figure based on JEMA (2020), "Vision for Electricity Storage Ver. 5."
- Regarding adjustment restrictions in each area, the model's assumptions are frequency control of plus-minus 2% of area demand, spinning reserve that can handle 1 GW of power sources going down, and supply reserve of 5% of area demand. Frequency restrictions and spinning reserve, it assumed by the model, are supplied only from online power plants, and supply reserve is secured with both online and offline plants.

Chart 1 Area Facility Capacity in the Sustainable Energy Mix



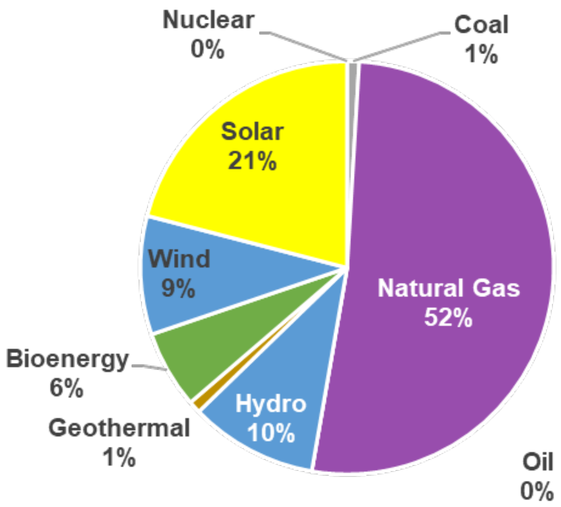
Source: Created by REI

2 Verification of supply stability

2.1 Electricity generation mix in FY2030

The results of our analysis of the sustainable energy mix based on the above model, data and parameters are as follows. First of all, the percentages of the FY2030 energy mix (transmission end) in Chart 2 show that renewable energy accounts for approximately 47.2% of total annual electricity supply. This figure is after deducting curtailments on solar and wind power. In the model's analysis, there were curtailments of 1.9% on solar power and wind power[6]. In these calculations, coal-fired power is retained as supply capacity in Hokkaido and Okinawa given the need to ensure supply stability. As a result, total annual electricity generated from coal-fired power is 8 TWh, but this represents a 98% decline compared to total electricity generated by coal-fired power in FY2010, which meets the standard for coal phase-out.

Chart 2 Annual Electricity Generation Makeup (Transmission End) in Sustainable Energy Mix



Source: Created by REI

2.2 Electricity genration mix in FY2030 (by area)

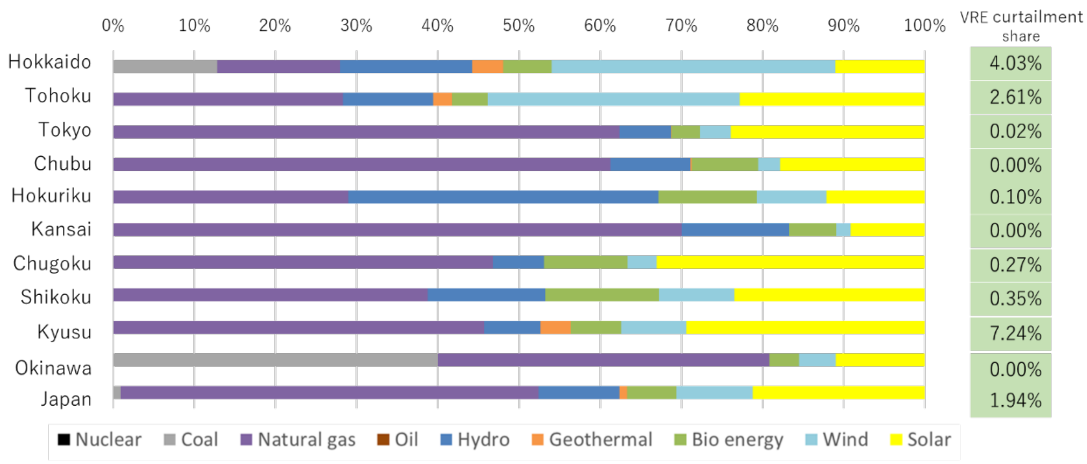
The FY2030 electricity generation mix (net-generation basis) in each grid area in the sustainable energy mix is shown in Chart 3. In the sustainable energy mix, a large amount of wind power is expected to be deployed in the Hokkaido and Tohoku areas, so wind power accounts for a large percentage of the mix in these areas. As discussed above in connection with parameters, in our calculations, we decided to distribute future solar power and wind power based on the current regional distribution of facility certifications and environmental assessments. As a result, renewable energy's percentage of the mix is low in three areas of Tokyo, Chubu, and Kansai, and is high in the other areas of Hokkaido, Tohoku, Hokuriku, Chugoku, Shikoku, and Kyushu. In the Hokkaido, Tohoku, and Hokuriku areas in particular, renewable energy, including hydropower,

[6] Curtailment rate = Curtailment amount / (Total solar power generation + Total wind power generation).

accounts for over 70% of total annual electricity generation. Chart 3 also shows curtailment rates in each region. The curtailment rate is particularly high in the Hokkaido, Tohoku, and Kyushu areas.

The renewable energy rate and curtailment rate in each area have a major impact on the distribution of future deployments of solar and wind power, a precondition of the model. It is possible that if this deployment distribution changes, the curtailment rate will decrease. At the present time, however, regional deployment trends for 2030 are not expected to change significantly given the status of facility certification and environmental assessments, the assumptions used for this analysis.

Chart 3 Annual Electricity Generation Makeup in Sustainable Energy Mix (Transmission end)

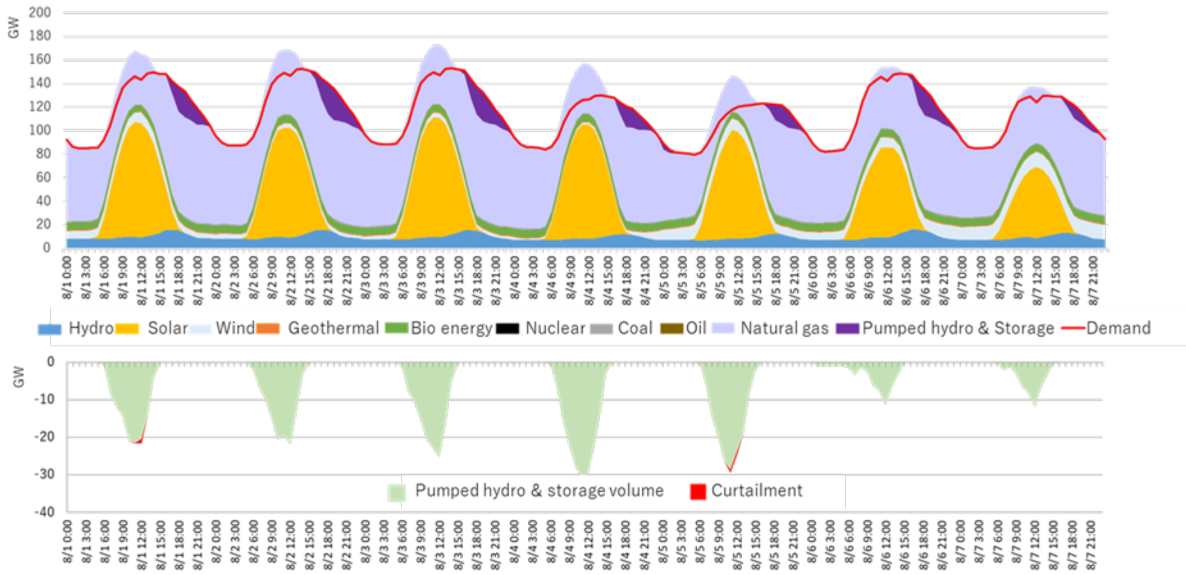


Source: Created by REI

2.3 Supply-demand structure during peak summer demand

Japan's overall supply-and-demand structure during the period of peak summer demand in FY2030 with the model's assumed sustainable energy mix is shown in Chart 4. The upper chart in Chart 4 shows electricity demand (red line) and output from each power source (color coded by fuel type), and the lower chart shows, as negatives, adjustments to supply capacity via pumped-storage pumping, battery storage, and curtailments. In the sustainable energy mix, solar power's share of electricity supply is extremely high during daytime hours in the period of peak summer demand. By contrast, it declines from evening through night, so substantial demand would need to be met with natural gas-fired power. This is called the 'duck curve' phenomenon, and one issue is how to avoid supply capacity shortages from evening through night at such times. The model's analysis found that supply capacity is adequately secured with adjustments using pumped-storage pumping and battery charging during the day (light green section on the negative part of the lower chart) and generating electricity from these sources from evening through night (dark purple section on upper chart).

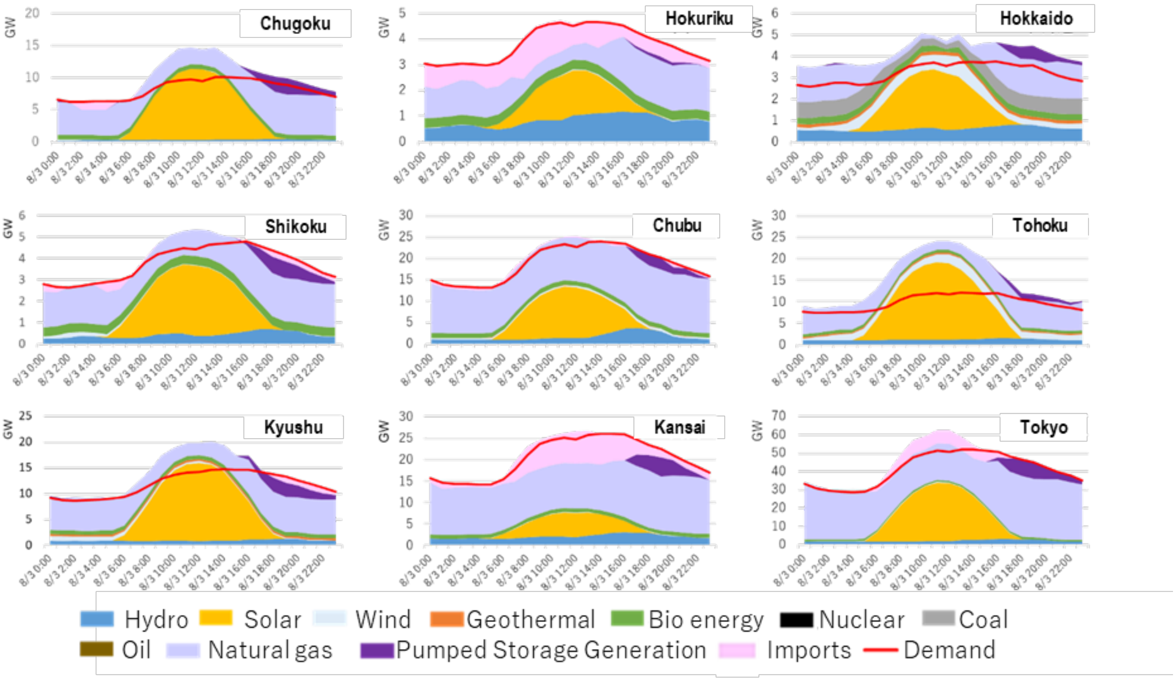
Chart 4 Japan's Overall Supply-Demand Structure During Peak Sumer Demand



Source: Created by REI

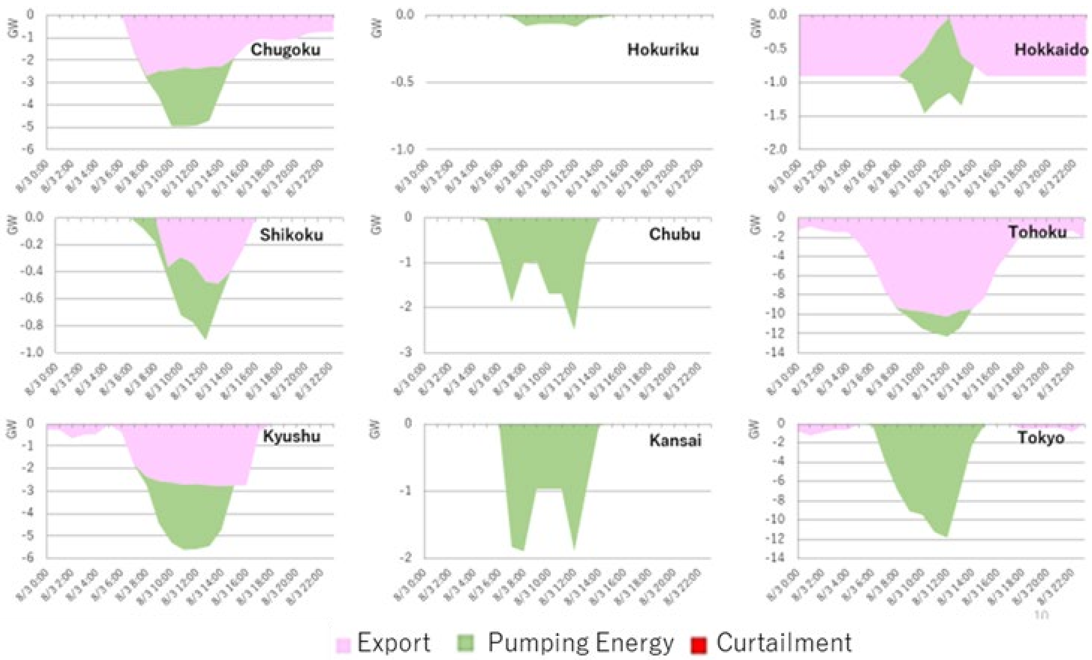
The supply-and-demand structures for each area for one day at the highest peak of demand are show in Chart 5 and Chart 6. Chart 5 shows demand (red line), supply from power sources (color-coded by fuel), and supply from other regions via interconnectors for each area, and Chart 6 shows adjustments via pumped-storage pumping, battery storage, and curtailments, and electricity transmission to other regions via interconnectors. Based on these calculations, we compiled changes in hourly capacity factor rates based on hourly output figures for solar and wind power in each area in FY2018. On this day, solar plants in the Tohoku and Hokkaido and the Chugoku, Shikoku, and Kyushu areas generated substantial output, but in the Kansai and the Hokuriku and Chubu areas, solar output tended to be small. As a result, electricity flowed from regions with supply surpluses to areas like Kansai and Hokuriku with low solar power output. This shows that interconnectors will be even more important for effective utilization of solar and wind power.

Chart 5 Area Supply-Demand Structure on Summer Day with Highest Demand



Source: Created by REI

Chart 6 Area Curtailments, Transmission to Other Regions, and Pumping Volume on Summer Day with Highest Demand

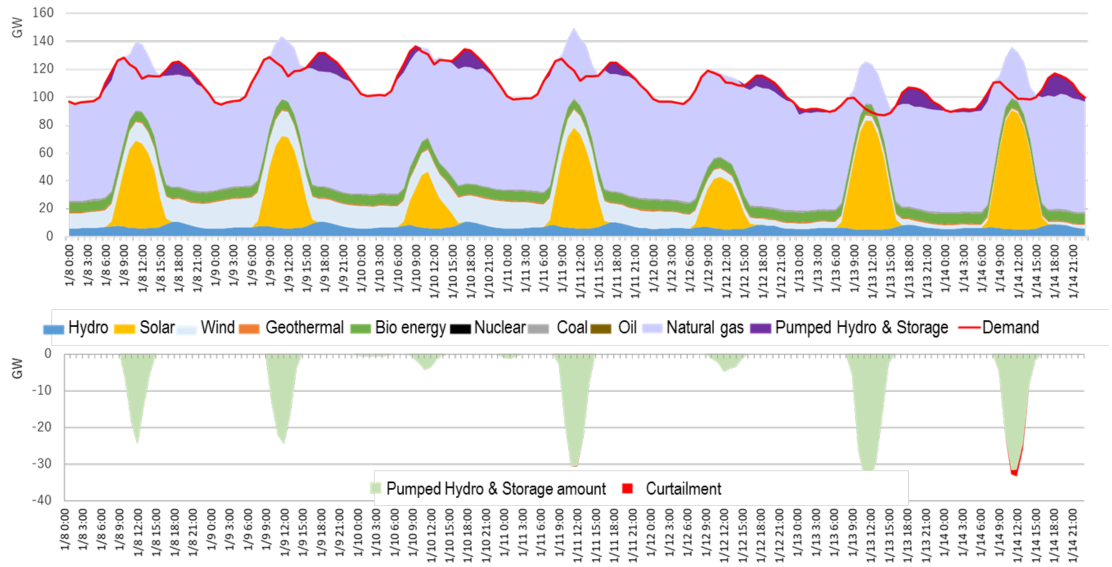


Source: Created by REI

2.4 Supply-demand structure during peak winter demand

In winter, just as in summer, securing supply capacity in the ‘duck curve’ from evening through night is an issue, and, moreover, daytime supply from solar power is less than the summer, so there is the possibility of higher reliance on natural gas-fired power. Japan’s overall structure of supply-and-demand during peak winter demand in FY2030 with the model’s sustainable energy mix is shown in Chart 7. In the sustainable energy mix, solar power is one of the main sources of electricity supply during the day, and during the day, pumped-storage pumping is conducted based on daytime solar power, so it contributes to supply from evening through night as well. On days when daytime supply from solar power is low, supply from wind power tends to rise, so increased deployment of wind power helps to mitigate the risk of supply shortages in winter. With the sustainable energy mix, the model suggests that for the period of peak winter demand as well it will be important to secure supply capacity through increased deployment of solar and wind power.

Chart 7 Japan’s Overall Supply-Demand Structure During Peak Winter Demand

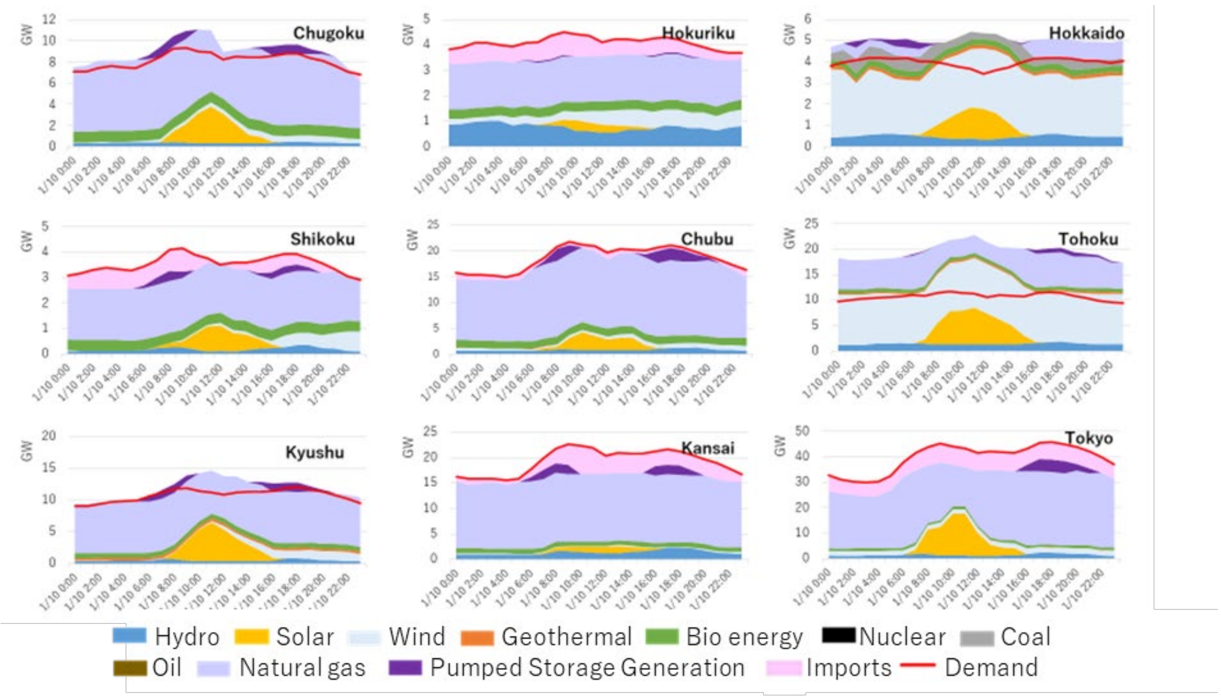


Source: Created by REI

Chart 8 shows the supply-and-demand structure in each area for one day when solar power supply is low during the period of peak winter demand. On this day, supply from solar power around the country is low and supply from natural-gas fired power is high. During such conditions, power supply in the Hokkaido and Tohoku areas, which, based on the assumptions, have extensive deployments of wind power facilities, is extremely high, and electricity flows to the Tokyo area. Chart 9 shows curtailments, transmission to other regions, and pumped-storage pumping on the same day. On days of peak winter demand, electricity interchange through interconnectors plays a more important role than supply-and-demand adjustments through pumped-storage in each area.

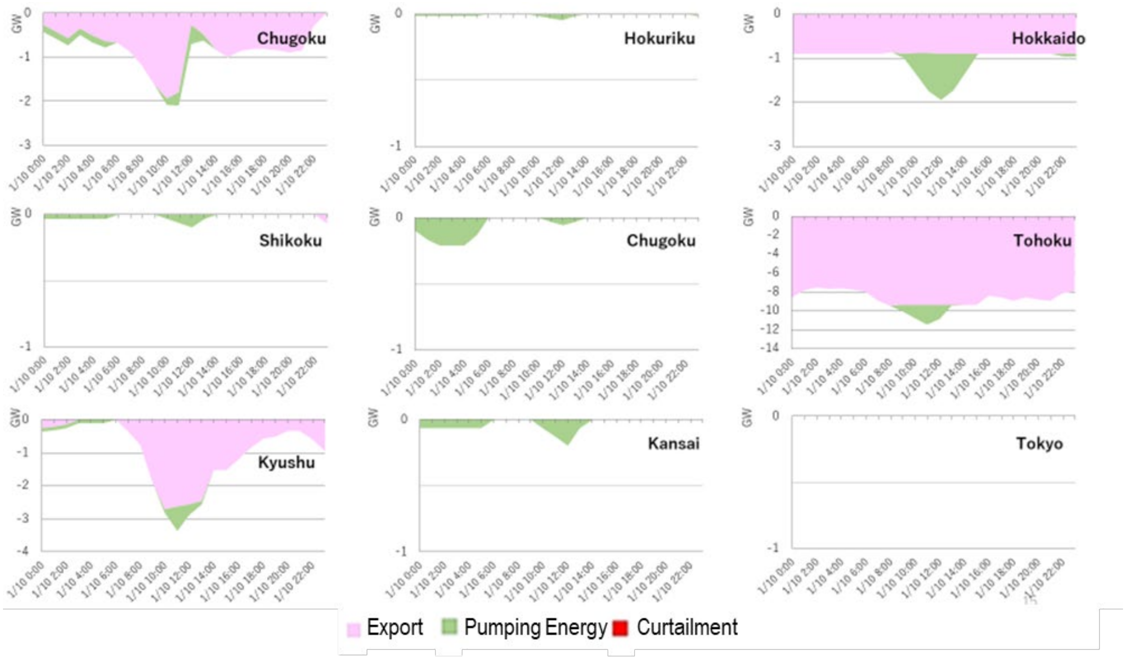
As we have seen, in the sustainable energy mix, supply capacity for peak winter and summer demand can be adequately secured through increased deployment of solar and wind power. Output from solar power and wind power at these times is very large, and it can be adequately and effectively utilized through use of electricity interchange via interconnectors between regions and pumped-storage, which suggests a low level of curtailments. In this sustainable energy mix, electricity demand is expected to be 7% lower than in FY2018. It is also possible that increases in electricity demand, record-hot summers or extremely cold winters, could make it necessary to utilize the coal-fired power (USC) available as reserve capacity. To completely eliminate coal-fired power will likely require further deployment of solar and wind power and government policies for increasing energy use efficiency.

Chart 8 Area Supply-Demand Structure on Winter Day with Highest Demand



Source: Created by REI

Chart 9 Area Curtailments, Transmission to Other Regions, and Pumping Volume on Winter Day with Highest Demand

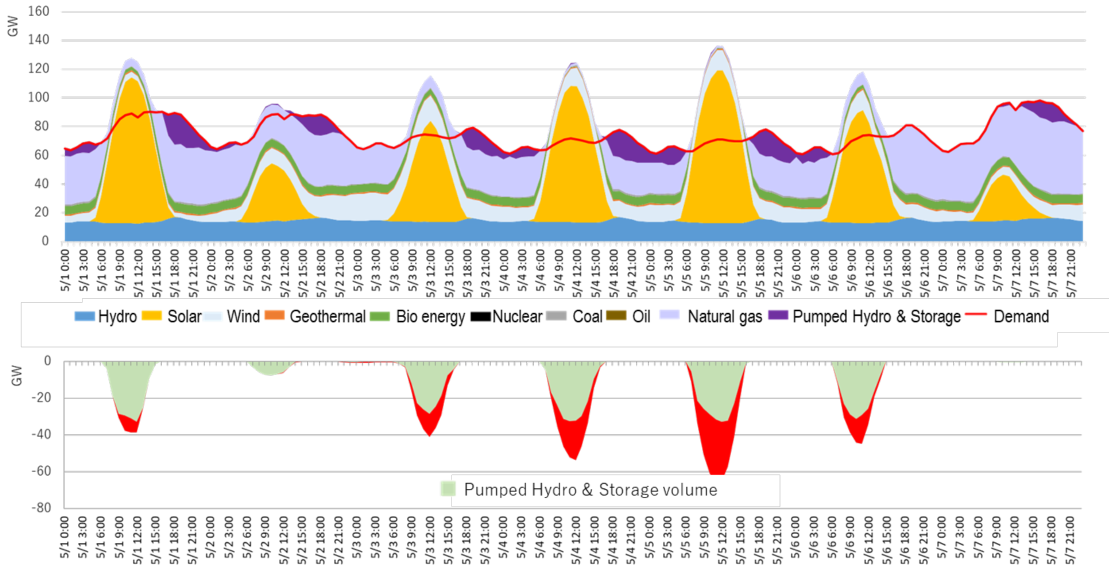


Source: Created by REI

2.5 Supply-demand structure during minimum spring demand

In the spring, electricity demand is low compared to the rest of the year, and electricity generated from solar power tends to increase, so there is the potential for major curtailments. Japan's overall structure of supply-and-demand during minimum spring demand in FY2030 in the sustainable energy mix is shown in Chart 10. In the sustainable energy mix's structure of spring supply-and-demand, electricity generated from solar power greatly exceeds electricity demand during daytime hours. Surplus electricity during the day is adjusted as much as possible using pumped-storage and then utilized as supply capacity from evening through night, but output that cannot be fully adjusted in this way is restricted (Chart 10, lower: red section).

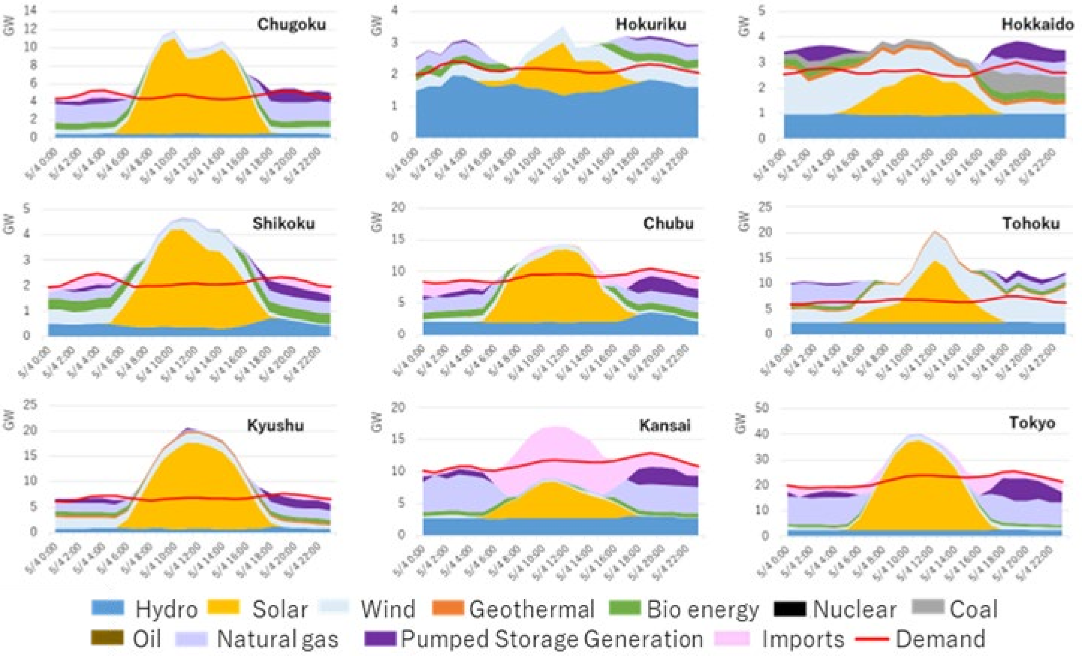
Chart 10 Japan's Overall Supply-Demand Structure During Minimum Spring Demand



Source: Created by REI

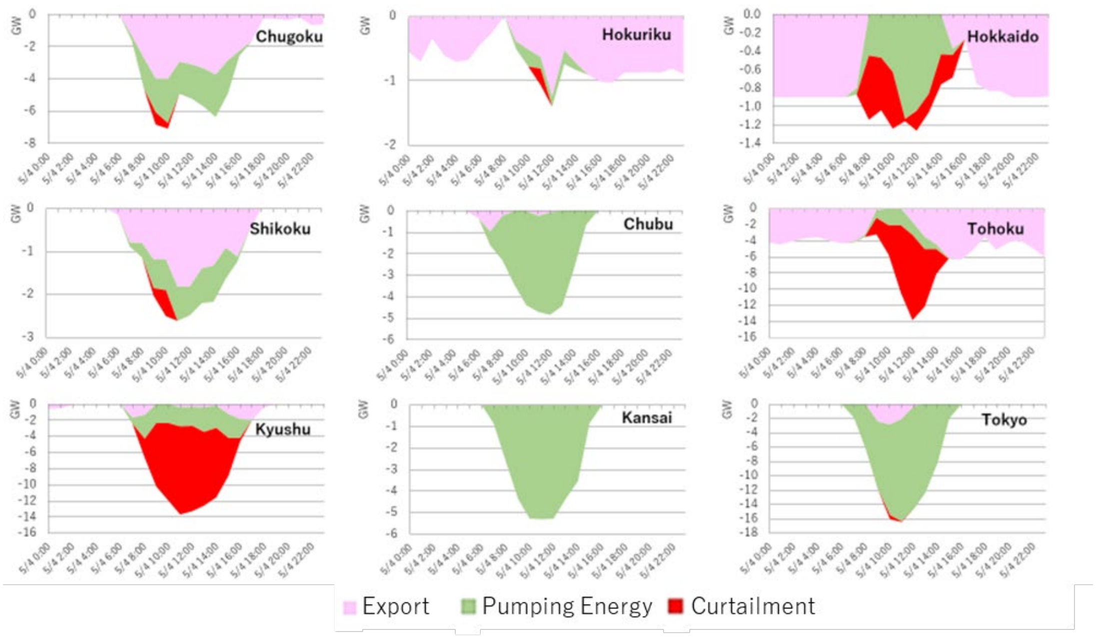
Chart 11 shows the supply-and-demand structure in each area for one day with low solar power supply during the period of minimum spring demand. On this day, electricity flows from Kyushu, Chugoku and Shikoku areas where solar power supply is high to the Kansai area where it was low. In the Hokkaido and Tohoku areas, supply of not only solar power but also wind power is high. Chart 12 shows curtailments, transmission to other regions, and pumped-storage pumping on the same day. It shows large curtailments in the Hokkaido, Tohoku, and Kyushu areas, but the surplus is adjusted through utilization of pumped-storage in the Tokyo, Kansai, and Chubu areas.

Chart 11 Area Supply-Demand Structure on Spring Day with Lowest Demand



Source: Created by REI

Chart 12 Area Curtailments, Transmission to Other Regions, and Pumping Volume on Spring Day with Lowest Demand



Source: Created by REI

2.6 Verification of supply stability

Having verified the supply-demand structure in the sustainable energy mix in this model, the results are as follows.

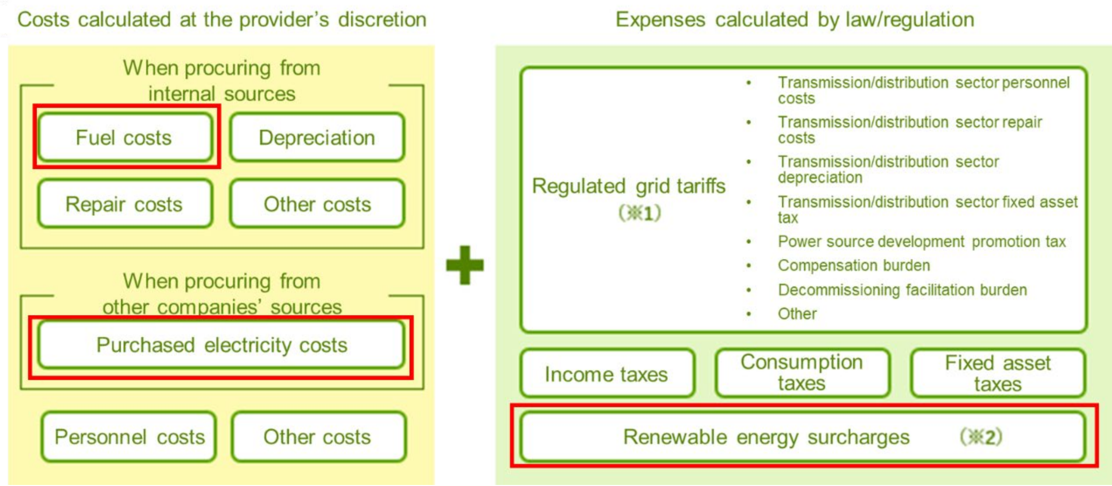
- Stable supply is possible even when aiming for zero nuclear power and a coal phase-out by FY2030.
- The analysis of the supply-and-demand structure during peak summer demand suggests that it is possible to secure supply capacity from evening through night in a 'duck curve' situation by making adjustments with daytime solar power supply and pumped-storage and with electricity interchange through interconnectors, and that it is possible to ensure supply stability even in a model that has the preconditions of securing balancing capacity and reserve capacity.
- It was shown that supply from daytime solar power is an important source of supply even during the period of peak winter demand. Supply from solar power decreases in the winter compared to the summer, but supply from wind power also increases, so supply capacity can be secured against maximum demand from evening through night. Supply from solar power during the day is low, so compared to the summer interchange between regions via interconnectors plays a more important role than pumped-storage.
- From the analysis of the supply-demand structure in spring, it was shown that large curtailments are necessary when demand is low. Predicting future deployment distribution based on current certified capacity under FiT and capacity in the process of EIA, this period is expected to require large curtailments in the Hokkaido, Tohoku, and Kyushu areas in particular, but, on the other hand, in areas with high demand like the Tokyo, Chubu, and Kansai areas, the amount of curtailment is expected to remain low. As a result, curtailments, as a national average, are just 1.9%. Depending on the precision of solar and wind power predictions, in actual operations, this figure may be larger. Going forward, efforts will be needed to minimize the amount of curtailment by increasing predictive precision and improving real-time control technologies.

3 Assessment of economic impacts (affordability assessment)

3.1 Scope of electricity costs

The government uses electricity costs as the standard to evaluate economy. According to the government, electricity costs are the total of fuel costs (thermal, nuclear, etc.) and renewable energy procurement costs. However, in terms of the component elements that determine electricity charges, the scope is narrow. According to the breakdown of electricity charges provided by the Agency for Natural Resources and Energy, of the elements shown that make up electricity charges (Chart 13), the scope used for evaluation of 'electricity costs' is the part boxed in red[7]. As shown in Chart 13, 'electricity costs' as defined by the government are only a portion of the various costs.

Chart 13 Breakdown of Costs in Electricity Charges



Source: Agency for Natural Resources and Energy, "Electricity Pricing Mechanism"
https://www.enecho.meti.go.jp/category/electricity_and_gas/electric/fee/stracture/pricing/

Moreover, though not currently included in electricity charges, other important costs are the social costs of CO_2 emissions (or, CO_2 reduction costs). Climate change caused by CO_2 emissions is raising the risk of disasters like heatwaves, torrential rains, forest fires and draught and inflicting major damage on society. To what extent these social losses caused by CO_2 emissions constitute costs is currently being studied around the world. According to social cost estimates made by the U.S. Environmental Protection Agency (EPA, 2013, revised 2016), average social costs in 2020 per one ton of CO_2 emissions were \$12, \$42, and \$62 (2007 dollar value basis) (discount rates of 5%, 3% and 2.5%, respectively). However, it has been pointed out that the U.S. government's figures are underestimated compared to the estimates of nearly every climate change expert[8].

[7] Fuel costs are the portion of 'fuel costs procured from internal power sources' and 'the cost of electricity purchased from other companies' power sources,' and renewable energy procurement costs are the total of a part (avoidable cost portion) of 'the cost of electricity purchased from other companies' and 'renewable energy surcharges.'

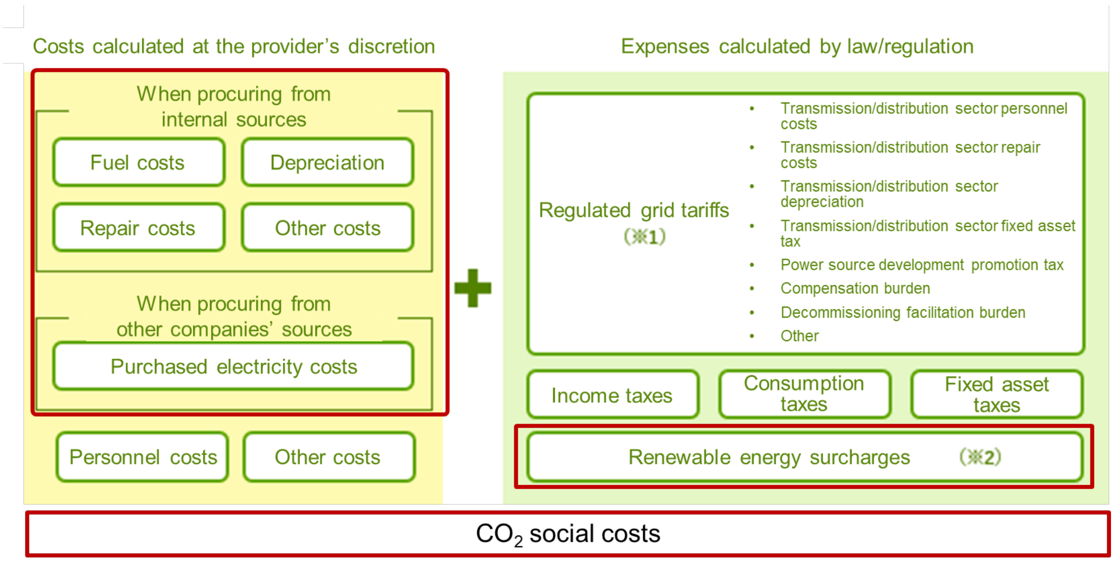
[8] Pindyck, R. S. (2019), "The social cost of carbon revisited," Journal of Environmental Economics and

While there is some variance in these estimates, the CO_2 social costs should be included in energy cost evaluations. In particular, the power sector accounts for approximately 40% of Japan's CO_2 emissions from energy, and it is the largest emitter of all sectors, so it should be valid to include the cost of emissions in electricity costs.

3.2 Scope of electricity costs considered by this report

The scope of electricity costs as defined by the government does not include important aspects that would normally be considered, so this study expands its scope. The scope is set at the main electricity procurement costs excluding regulated grid tariffs and taxes (aggregate of costs when procured from internal power sources and when procured from other companies' sources), renewable energy surcharges, and social costs (in the red box on Chart 14). The reason regulated grid tariffs (a transmission/distribution cost) are not included in this scope is that in the sustainable energy mix the only enhancements expected are those to transmission grids that are already planned; it does not assume any new additional investment in transmission.

Chart 14 Study's Scope of Costs in Electricity Charges (red square)



Source: Agency for Natural Resources and Energy, "Electricity Pricing Mechanism"
https://www.enecho.meti.go.jp/category/electricity_and_gas/electric/fee/stracture/pricing/

Management, 94, pp.140-160. The average of social costs (in the distribution with the highest coefficient of determination) derived by 386 scientists has been compiled in Pindyck (2019). That figure is \$291/CO_2-ton.

3.4 Method used for considering electricity costs

Electricity procurement costs

Electricity is procured in various ways; providers use electricity they generate themselves, they purchase electricity from other companies, and they purchase it on the wholesale electricity market. Of these procurement methods, the one where prices are clear is the wholesale market. Accordingly, this study calculates electricity procurement costs based on wholesale electricity prices (spot prices). Wholesale electricity prices are determined every thirty minutes at the amount where demand and supply (marginal costs) meet (singe-price auction).

Wholesale prices in FY2030 in the sustainable energy mix are estimated by recreating the single-price auction using the same methods as currently used to determine prices. Fuel prices use figures in 2030 for Japan in IEA (2019)'s 'Stated Policies Scenario' (2018 USD values)[9].

Renewable energy surcharges

Renewable energy surcharges are broadly collected from electricity consumers based on the Renewable Energy Special Measures Act in order to offset the cost of electricity from renewable energy sources. Specifically, the surcharge is renewable electricity[10] procurement costs minus the portion borne by electricity providers (avoidable costs) and the unit price is determined by Ministry of Economy, Trade and Industry ordinance[11]. For example, the FY2020 renewable energy surcharge's unit price has been set at 2.98 yen/kWh.

Procurement costs of renewable electricity under Feed-in Tariffs are derived by multiplying the procurement price by the amount of electricity acquired. Assumptions for acquisition prices by certification fiscal year (includes the prices of winning bids at electricity auctions) are shown in the chart below. For the various power sources, we estimated generation unit prices at model plants commencing operations in FY2025 and FY2030 and incorporated these into acquisition prices. Estimated acquisition prices for power facilities going online in FY2030 are 7 yen/kWh for solar power of less than 10 kW, 6 yen/kWh for solar power (commercial), 7 yen/kWh for onshore wind power, and 6 yen/kWh for offshore wind power. Unit prices for electricity generated by model plants were estimated based on provider cost data and interviews for each cost component. Considering the time lag until the start of operations, acquisition prices in the certification fiscal year are assumed. The consumption tax is calculated at 10%.

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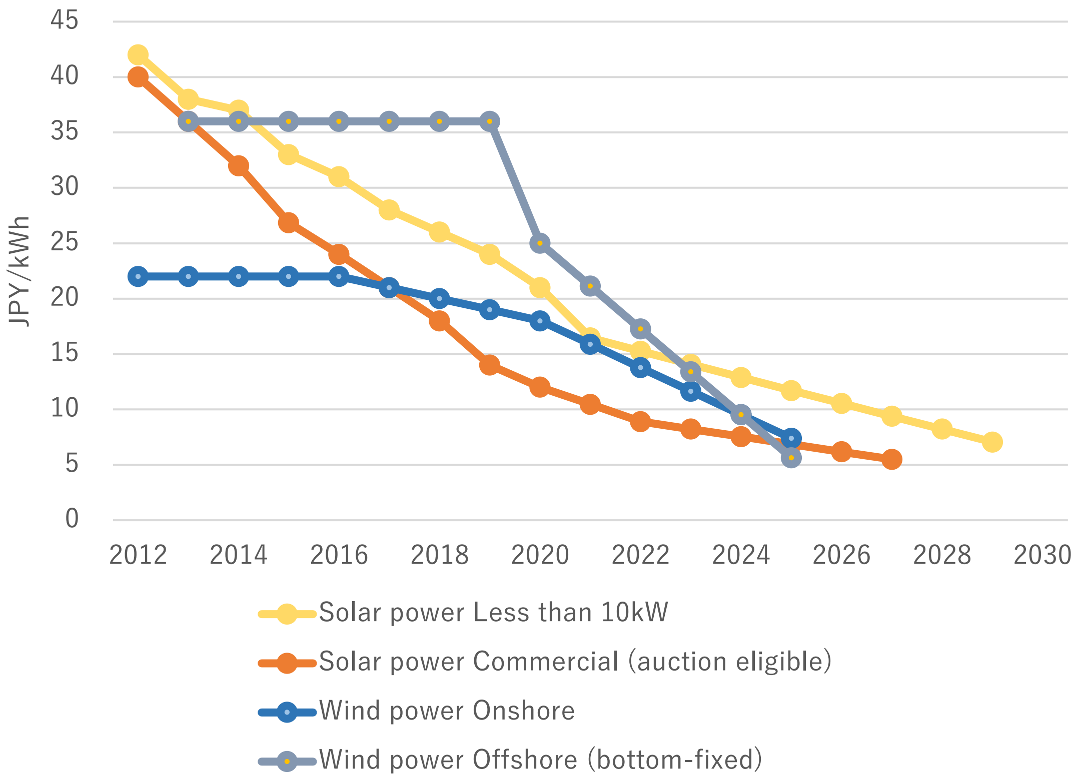
[9] IEA (2019) World Energy Outlook, p.756, B.4 Fossil fuel prices.[10] More accurately, it is limited to electricity generated by operationally certified facilities under the Renewable Energy Special Measures Act. For this reason, residential solar (less than 10 kW), for which the acquisition period under the act has expired, is excluded from the scope of procurement costs.

[10] More accurately, it is limited to electricity generated by operationally certified facilities under the Renewable Energy Special Measures Act. For this reason, residential solar (less than 10 kW), for which the acquisition period under the act has expired, is excluded from the scope of procurement costs.

[11] Renewable Energy Special Measures Act: Article 31 and Article 32.

Chart 15 Assumptions for Acquisition Prices and Winning Bids by Certification Fiscal Year



Source: Created by REI

Renewable energy surcharges are acquisition prices net of avoidable costs. Avoidable costs are calculated using FY2030 wholesale electricity prices, the same prices used when calculating electricity procurement costs.

CO_2 social costs

Though criticized as underestimated, we use the conservative estimates made by the U.S. Environmental Protection Agency (EPA, 2016) (Table 3). Regarding the discount rate, we use the figures with a rate of 3%. In this case, the figures for 2020 social costs ($42/$CO_2$-tons) and 2030 costs ($50/CO_2-tons) are converted to yen values in 2018 and these are multiplied by CO_2 emissions from the power sector in FY2019 and FY2030 to determine the costs. As a result, unit of CO_2 social costs for 2020 were 5,598 yen/CO_2-tons[12], and for 2030, 6,664 yen/CO_2-tons.

[12] Using the national average of CO_2 emission factors for electricity providers in FY2019 (0.445 kg/kWh), the social cost per 1 kWh of CO_2 in 2020 comes to 2.49 yen/kWh. The national average of CO_2 emission factors refers to Ministry of the Environment (2021), "Announcement of Basic Emissions Factors and Adjusted Emissions Factors for Electricity Providers in FY2019" (http://www.env.go.jp/press/108826.html).

Table 4 CO_2 Social Cost Estimates (U.S. EPA)

Revised Social Cost of CO_2 2010-2050 (in 2007 dollars per metric ton of CO_2)

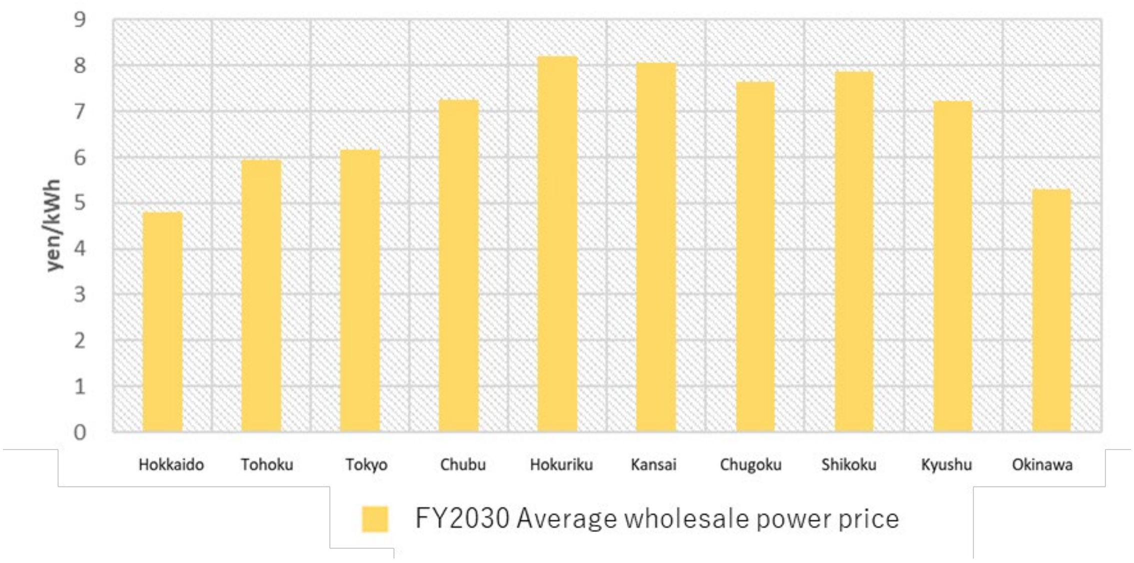
Discount Rate Year	5.0% Avg	3.0% Avg	2.5% Avg	3.0% 95th
2010	10	31	50	86
2015	11	36	56	105
2020	12	42	62	123
2025	14	46	68	138
2030	16	50	73	152
2035	18	55	78	168
2040	21	60	84	183
2045	23	64	89	197
2050	26	69	95	212

Source: EPA (2016)

3.5 Results of considering electricity costs

The results are shown in Chart 16. There are regional differences in average wholesale electricity prices, which show electricity procurement costs. Overall, wholesale electricity prices in the East Japan area (Hokkaido, Tohoku, Tokyo) are low, and prices in the West Japan area are relatively high.

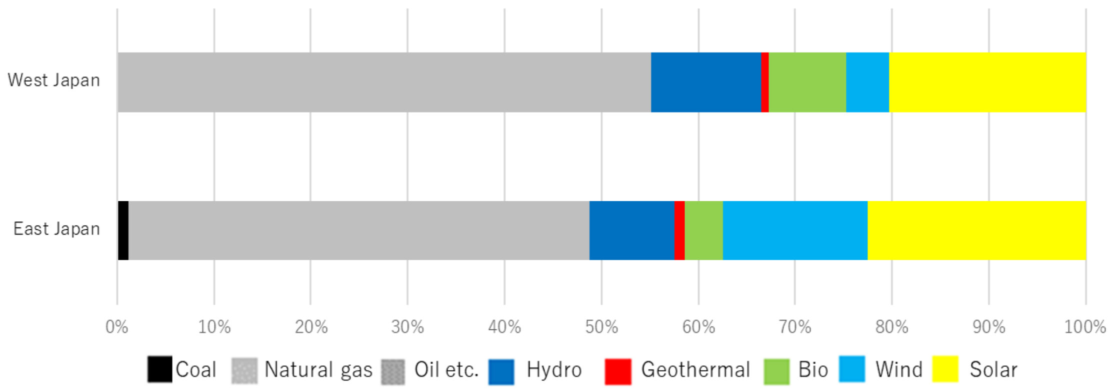
Chart 16 FY2030 Average Wholesale Electricity Prices by Area



Source: Created by REI

Comparing the electricity generation mix in these regions, there are significant differences in wind power share between East and West Japan (Chart 17). In the sustainable energy mix, wind power deployment is expected to make significant progress, but in the West Japan area, wind deployment is less than East Japan, so electricity supply from wind power is also low. By contrast, in the East Japan area, many wind power plants are expected to be built in Hokkaido and Tohoku areas, which have ample wind resources, and after that electricity supply from them will be substantial. If electricity generated in East Japan can be supplied without restrictions to West Japan, theoretically, price differences between the two regions would disappear, but in actuality, there are capacity restrictions on interconnectors, so transmission restrictions occur. The differences in renewable electricity supply volume and these transmission restrictions are related to the price differences between areas.

Chart 17 Electricity generation mix by Area (FY2030)



Source: Created by REI

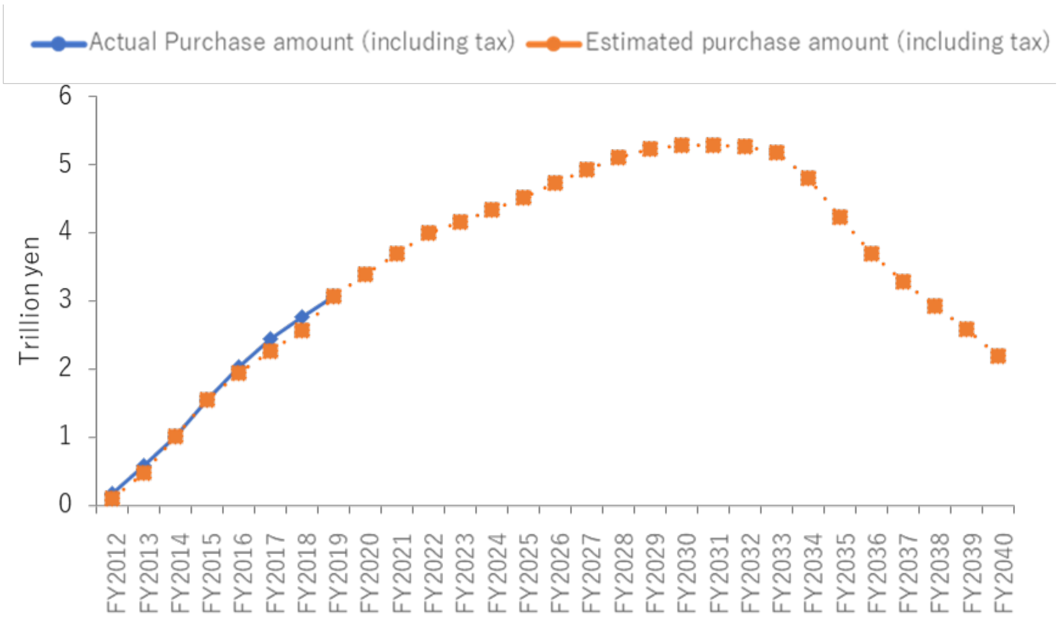
Renewable energy surcharges

Total procurement costs in FY2030 in the sustainable energy mix are expected to reach approximately 4.8 trillion yen (with consumption tax, approx. 5.3 trillion yen). Renewable energy surcharges excluding avoidable costs are 4.0 trillion yen with taxes. The surcharge unit price is expected to reach 4.68 yen/kWh.

In the sustainable energy mix, total procurement costs of renewable electricity under FiT exceed the 4 trillion yen upper limit set by the government for FY2030 by 0.8 trillion yen. However, as shown in Chart 14, total procurement costs themselves are only a portion of electricity costs. What is important is whether or not total electricity costs put an excessive burden on consumers. This point will be taken up below in conjunction with electricity procurement costs.

Also, as is shown below, procurement costs are highest in the early 2030's; after this peak they are projected to rapidly decline (Chart 18). This is because in 2030 solar power (10 kW and larger) certified at the high prices of 40 yen/kWh or 36 yen/kWh in FY2012 or FY2013 is still being purchased; from the mid-2030's, the price declines sharply. This is why renewable energy surcharges will be high only for a limited time, from the 2020's to early 2030's.

Chart 18 Actual Procurement costs Under Renewable Energy Special Measures Act and Estimates in Sustainable Energy Mix

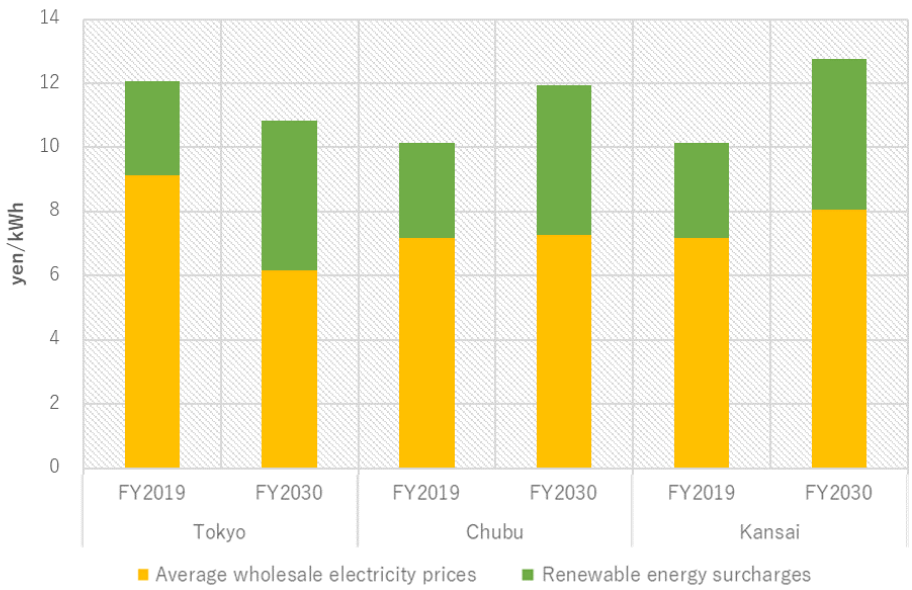


Source: Created by REI

Total electricity costs

Wholesale electricity unit prices, discussed above, and electricity unit prices with the renewable energy surcharge unit price (yen/kWh) are shown for each area (Chart 19). These are shown together with FY2019 figures for three areas of Tokyo, Chubu, and Kansai. In the Chubu area, wholesale electricity unit prices in FY2019 and FY2030 are nearly the same, but the increase in renewable energy surcharges results in increasing the electricity unit price. In the Kansai area, wholesale electricity unit prices themselves are also higher than in FY2019, so the increase in electricity prices is relatively large. Conversely, in the Tokyo area, wholesale electricity prices are significantly lower than FY2019, so regardless of the increase in the renewable energy surcharge, the electricity unit price is more affordable than in FY2019.

Chart 19 FY2019 and FY2030 Electricity Unit Price Comparison (Tokyo, Chubu, Kansai Area)

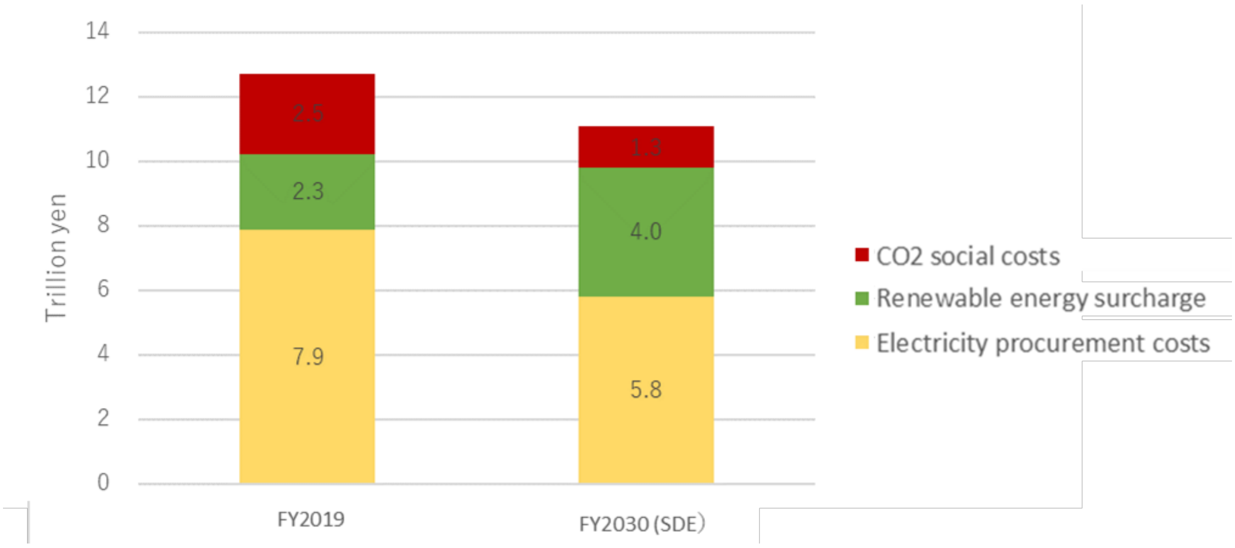


Note: Electricity unit prices do not include regulated grid tariffs or taxes.
Source: Created by REI

Along with electricity unit prices, we will also consider total electricity costs. Calculating electricity procurement costs from estimated wholesale electricity prices, they came to 5.8 trillion yen in FY2030. Renewable electricity surcharges, as stated above, are estimated at 4.0 trillion yen (procurement costs with tax are 5.3 trillion yen). CO_2 social costs are reduced by 1.3 trillion yen (CO_2 social unit cost of 6,664 yen/CO_2-tons) through phasing out coal and promoting renewable energy and totaled 11.1 trillion yen (Chart 20). Therefore in FY2030, renewable energy surcharges will account for a large proportion of electricity costs, but around the mid-2030's, as discussed above, renewable electricity procurement costs are projected to decline rapidly. As a result, from the mid-2030's, electricity costs are projected to decrease rapidly.

For comparison, electricity costs in FY2019 (electricity procurement costs + renewable energy surcharges + CO_2 social costs) were 12.7 trillion yen. Including social costs (CO_2 social unit costs: 5,598 yen/CO_2-ton), electricity costs in FY2030 are reduced by 1.6 trillion yen compared to FY2019. Not including social costs, FY2030 electricity costs (9.8 trillion yen) were slightly lower than the FY2019 figure (10.2 trillion yen).

Chart 20 Comparison of FY2019 and FY2030 Electricity Costs



Note: FY2030 (SDE) refers to the 'FY2030 sustainable energy mix.'
Source: Created by REI

Electricity procurement costs in FY2019 are calculated by multiplying the hourly wholesale electricity price in each area in 2019 by hourly electricity demand in each area. Procurement costs for the portion of electricity consumed onsite are calculated by multiplying the annual average wholesale electricity price in each area by consumption volume. As a result, electricity procurement costs in FY2019 rise to 7.9 trillion yen. Renewable energy surcharges in FY2019 were 2.3 trillion yen[13].

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[13] Income on deposit payments received is from Green Investment Promotion Organization, "FY2019 Settlement of Accounts."

4 Conclusions and issues going forward

As we have seen, the considerations here suggest that it is possible to overcome the two issues raised in connection with ‘the sustainable energy mix’ proposed by REI in August 2020, supply stability and economy (affordable energy supply).

First, on the issue of supply stability, this study suggests the possibility of maintaining the balance of supply and demand in FY2030 by using renewable energy for 45% of electricity supply and with virtually no reliance on nuclear or coal-fired power, once called baseload power sources. In order to maintain an even more stable supply-and-demand balance, promoting further deployment of wind power and other renewable sources and effectively utilizing interconnectors will be extremely beneficial, and deployment of storage batteries will also be important. This study has found that increasing wind power in particular, whose supply capacity is relatively stable and increases in the winter months, will be extremely important for realizing stable supply.

Further issues in the analysis of supply stability in the sustainable energy mix include further considerations for the establishment of concrete supply-and-demand operating methods.

First, the verification conducted by this study used a model simulating each electric grid area and interconnectors between them. In order to analyze the complex processing of electricity currents on intra-regional grids, concrete operating methods for ‘connect-and-manage,’ and their impact, all of which are currently being considered, analysis is needed using a model that simulates an intra-regional grid.

Secondly, this study set parameters for securing reserve and balancing capacity within a model that had the constraint of supply-and-demand balanced hourly. Further verification is needed on the feasibility of maintaining stability when power sources go offline, or a grid accident occurs. This would have to involve using a grid model to verify whether or not frequency and voltage fluctuations could be kept within the scope of tolerance in the case of a down power source or grid accident. To verify this using a grid model, more detailed data would be needed on intra-regional grids and the balancing capacity of individual power plants, after incorporating the frequency and voltage control functions of wind and solar power facilities. Currently, grid codes are under consideration and progress is being made in releasing grid data, but going forward more data disclosure and more studies based on this data are needed to more concretely verify issues related to future supply stability.

From an economic point of view, it was found that even with zero nuclear power and a coal phase-out electricity costs in the sustainable energy mix (electricity procurement costs + renewable energy surcharges) could be lower than FY2019. Adding the CO_2 social costs into the equation, it was found that the sustainable energy mix has the potential to reduce electricity costs by 12% compared to FY2019.

We should note that achieving zero nuclear power and a coal phase-out, as assumed in the sustainable energy mix, will require additional policy measures by the government. It is possible that, along with additional regulations, compensation will be needed for decommissioning power plants, and if this is the case, additional policy costs would be incurred. On this point, further considerations are needed on each policy option available.

Another point that should be noted is that the ability to rein in electricity costs in the sustainable energy mix is premised on achieving steady cost reductions in renewable electricity. What needs to be considered is wind power cost projections. There are various technologies used around the world to reduce wind power generation costs, including larger turbines. This study makes price estimates with the expectation that large wind turbines will be effectively deployed. Whether or not these cost reductions can actually be achieved in Japan will require further detailed considerations going forward.

Also, in the sustainable energy mix, natural gas will have a larger role to play for a period of time. This study used fuel price projections from IEA (2019), but in reality, prices could be higher or lower due to a variety of factors. Whether or not to incorporate these price fluctuations needs to be separately considered.

Achieving carbon neutrality in 2050 is now finally Japan's goal as established by the government. To reach this goal will require raising the current target for renewable energy in 2030 of 22-24% by around twofold, as is being called for by many companies and local governments. REI's proposal in August 2020 and this study show that it is possible both technologically and economically to raise the target to this degree.

From the standpoint of power source development and power system conversion, the year of 2030 is the immediate future. Ten years has passed since the Great East Japan Earthquake of March 2011, and renewable energy development in Japan has made progress, as has the energy transition, but ahead of 2030, we need to raise the pace of reform by two or three times with our eyes set on a sustainable energy mix. The government's traditional energy policy which persisted in nuclear and coal-fired power, must be fundamentally revamped. Doing so would be proof that Japan is truly committed to the global effort to avert a severe climate crisis.

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Verification of Electricity Supply-Demand Balance and Costs in 2030

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