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RENEWABLE ENERGY INSTITUTE

Energy Transition Scenarios for Decarbonization

Based on 80% Renewables Electricity by 2035

August 2024

Acknowledgments

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About 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.

Introduction

A new Basic Energy Plan is being considered and to be finalized early next year. This discussion is critically instrumental in shaping the future direction of Japan's economy and its support for its citizens. For instance, one choice might result in higher energy prices, potentially relocating factories and industries abroad. Conversely, another choice might exacerbate the ongoing global climate change problem. It is imperative for Japan to remain a technologically developed country in the future and preserve its domestic industrial infrastructure, but it must simultaneously pursue decarbonization.

This report outlines measures to reduce CO_2 emissions by at least 65% from the 2019 level by 2035, in line with the IPCC's 1.5°C scenario, maintaining steelmaking and other manufacturing industries in Japan while also attracting new industries such as data centers and semiconductor plants. Electrifying industry is crucial for achieving this while also pursuing decarbonization. Some believe that nuclear power will be used to supply this electricity; however, our scenario indicates that the necessary power to electrify Japan's industry can be supplied affordably from renewables, eliminating the need for nuclear power.

Renewables have been criticized as an "unreliable source." However, this conventional wisdom is being overturned by improvements in power-grid technology and cross-regional operation that have supported stability of supply, and in recent years, information technology (IT), including AI, and the global decline in storage battery prices particularly in the past few years. It is becoming economically feasible to store electricity when there is a surplus of renewables generation and to use it when there is a shortage. The results of the electricity simulation conducted for this scenario show that the massively installed storage batteries store the surplus of solar power during the day and discharge it at night. Our results also suggest that wind power surpluses could be used to produce hydrogen domestically.

To achieve the 2035 vision in this scenario, it's vital to prioritize the early and substantial integration of renewables into the national plan outlined in the Basic Energy Plan, currently under discussion. This will necessitate implementing regulatory reforms and promoting renewable energy use. Furthermore, it's essential to clearly outline the use of storage batteries.

Renewable energy is continually strengthening Japan's energy landscape. We can enhance energy security, drive decarbonisation, and sustain Japan's industrial base by harnessing these resources. Maximising the use of renewables is crucial for steering Japan's economy towards a bright future.

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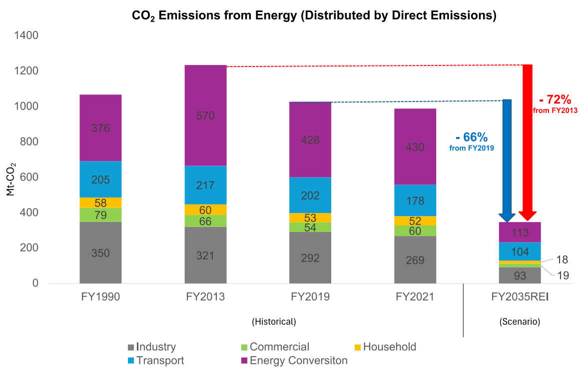
Summary

In this analysis, we develop a consistent vision of how Japan can reduce its CO_2 emissions by 65% (relative to FY2019) by FY2035. This includes a simulation that shows that significantly **increasing the quantity of storage batteries and grid interconnection** makes it possible to supply electricity 24 hours a day, 365 days a year based on a mix of 80% renewable energy (RE), including 50% variable renewables (VRE).[1]

Achieving a 66% CO_2 reduction by 2035 without an industrial hollowing-out

Japan's current steady progress toward 80% renewables by 2035 will enable the decarbonization of domestic manufacturing, including steel production. At the same time, it will stimulate the location of **data centers, semiconductor plants, and other new industries that commit to using renewable electricity**. In other words, this would permit decarbonization without an industrial hollowing-out. **Higher demand for the construction of infrastructure, such as offshore wind farms and power transmission lines**, can also be expected.

Fig. S- 1 Comparison of Energy-related CO_2 Emissions, Past versus Scenario: 66% Reduction by FY2035 (relative to FY2019)

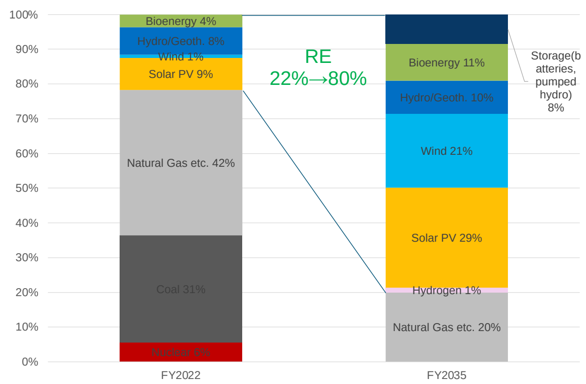


Even if economic activity remains comparable with the 2030 level projected in the 6th Basic Energy Plan, a 66% reduction in energy-derived CO_2 emissions in FY2035 (relative to FY2019) can be envisioned, by **conversion to electric steel furnaces**, **electrification and efficiency improvements** in industrial, household, and transportation sectors, the utilization of **renewable energy sources for 80% of electricity** production, and **steady diffusion of ZEB/ZEH**[2] **buildings**. While energy efficiency increased at an annual rate of 1.9% from FY2013 to FY2021, we estimate it to grow by 4.1% between FY2021 and FY2035 (thereby **doubling the energy efficiency improvement rate**).

80% of electricity from renewable sources

Even when 80% of electricity is produced from renewables, it will still be possible to meet hourly power supply requirements. In order to achieve it, grid interconnection between Hokkaido and Tokyo need to be enhanced than what we can expect from the master plan of the Organization for Cross-regional Coordination of Transmission Operators (OCCTO), which was based on the 46-48% renewable ratio by 2050. Our scenario assumes that substantial progress in the development of offshore wind power in Hokkaido and Tohoku will help to achieve 80% renewable electricity by 2035: significantly more ambitious than the assumption underlying the OCCTO Master Plan.

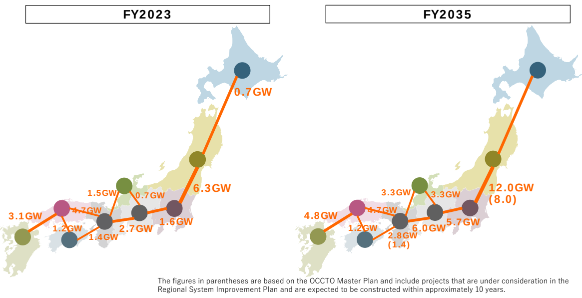
Fig. S- 2 Electricity Mix, Current versus 2035 Scenario with 80% Renewables (results)



[1] The simulation assumes the use of existing natural gas and other thermal power generation facilities (excluding coal) but does not assume any new construction.

[2] ZEB = (Net) Zero Energy Building; ZEH = (Net) Zero Energy House

Fig. S- 3 Assumption for Grid Enhancement



The required capacity of renewable energy systems is 3.3 times higher under our scenario. An analysis we presented in 2023 outlines how this can be achieved in detail.[3] It is assumed that to provide the required storage battery capacity, 15% of EVs will be used (12 GW/36 GWh), along with grid scale battery storage (60 GW/148 GWh), for a total storage capacity of 72 GW/184 GWh.

Fig. S- 4 Assumption for Renewable-related Capacity (Increases by 3.3 times)

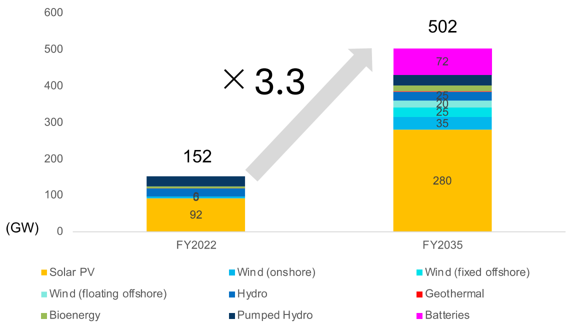


Fig. S- 5
Summer Electricity Supply: Past versus Scenario

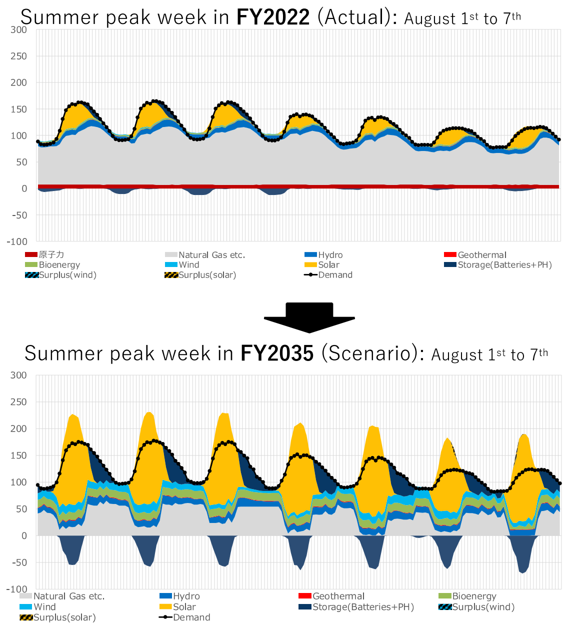
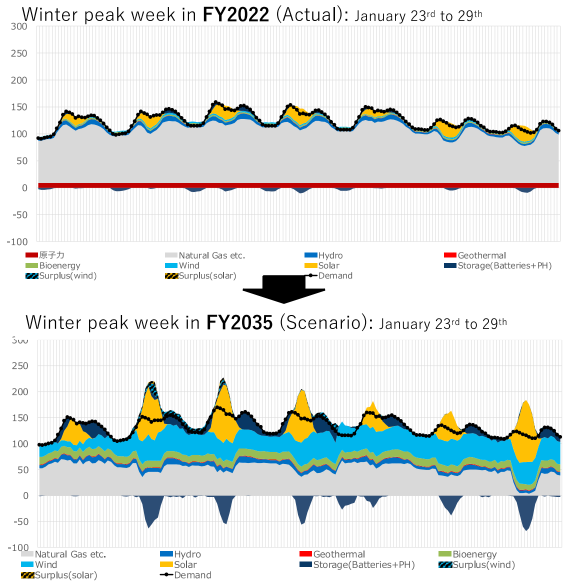


Fig. S- 6 Winter Electricity Supply: Past versus Scenario



A look at hourly power supply in summer shows that surplus solar energy is stored in batteries to be utilized in the evening or later. In winter, wind power makes up a higher proportion of total power, and while storage batteries are still used, less utilized than in summer.

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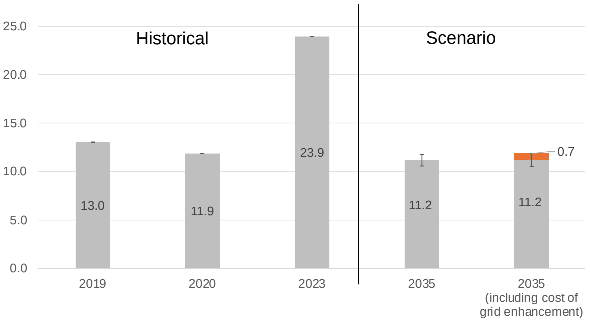
[3] See *Proposal for the 2035 Energy Mix (First Edition)* (April 2023) and *Japan's Offshore Wind Power Potential: Territorial Sea and Exclusive Economic Zone* (November 2023), both by Renewable Energy Institute.

Power generation costs are estimated to be **within pre-invasion to Ukraine levels, even with the inclusion of storage battery and grid enhancement expenses**. If the complementary effect of the various renewables in the mix of renewable sources and the fact that storage batteries, wind, and solar power can all contribute to the balancing power are taken into account, the "integrated cost" of the electric power system as a whole is unlikely to be high. **And the impact of any surge in fossil fuel prices to the generation cost with more renewables would certainly be small**.

Fig. S- 7 Power Generation Costs (Result)



Next Basic Energy Plan must be centered on renewable energy

To increase the proportion of electricity generated from renewable energy sources from the current 22% (FY2022) to 80% in 13 years, it is essential for Japan to set a clear direction in its new Basic Energy Plan, formulating a national energy strategy that centers renewable energy with its plan for integration. This will allow companies and investors to plan their operations in Japan with confidence. For example, to achieve the scale of offshore wind power envisaged in this scenario, by the end of this decade it will be necessary to designate 40 GW worth of marine area for offshore development and decide on the developers.

Accelerating the deployment of renewable energy

Accelerating the deployment of renewable energy systems necessitates regulatory reforms, to improve grid access, improve management of curtailment, unify and streamline regulations and procedures, digitalize assessment-related information, and extend the period for the conversion of farmland. To ensure the fairness and transparency of grid access and utilization, it is also important to enhance the independence of power transmission and distribution businesses by imposing strict separation rules and strict monitoring.

To promote the deployment of renewables and accelerate investments to match the level of decarbonization that is occurring around the world, it is vital that carbon price levels are predictable enough to provide sufficient economic incentives. Companies can only invest in projects if they can foresee a profit. Adequate carbon prices make investments in decarbonization profitable.

In the face of such a dramatic structural change, it is also important to ensure a just transition, particularly by providing a managed phase-out mechanism for coal-fired power.

Japanese technology contributing to worldwide power innovation

By its nature, renewable energy is domestically produced energy. It has been demonstrated that even without nuclear power[4] or zero-emission thermal power,[5] the goal of 80% renewables can be achieved through cheaper solar power, wind power, and storage batteries.

Renewable energy, once criticized for being expensive and unreliable, has become a cheap, predictable, and dependable power source. In large part, this is thanks to information technology (IT). Transitioning quickly to an electric power system of a new generation can pave the way for Japan to develop advanced technological capabilities that can benefit the rest of the world.

[4] It is necessary to distinguish between restarting existing nuclear power plants and constructing new plants in terms of cost. The maximum share of electricity that can be generated by restarting nuclear plants (assuming all applications to restart, operate, or extend operation are approved, with a plant capacity factor of 70%) is around 11%. The share under the current condition (considering only already approved applications and assuming a plant capacity factor of 70%) is 5%. Construction of new plants would be very costly and extremely difficult in terms of acceptability.

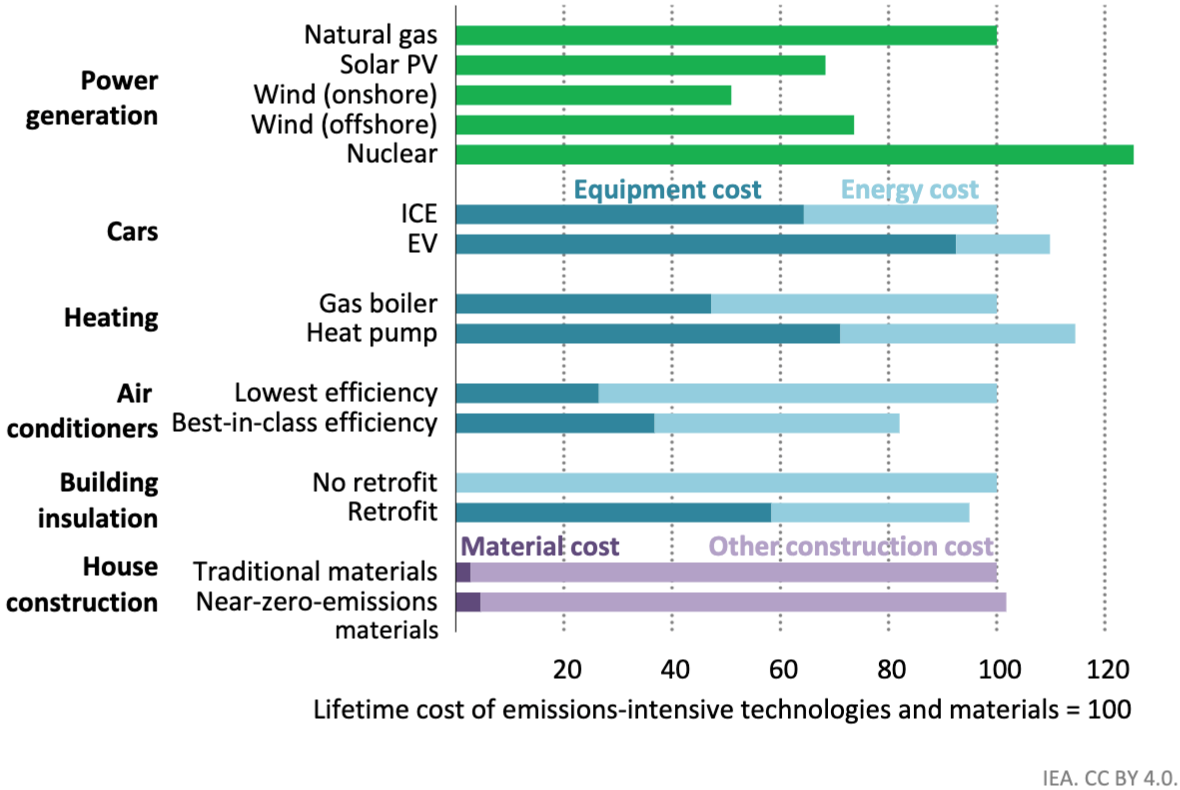
[5] For now, the cost of zero-emission thermal power is known to be high. In the case of imported hydrogen, it also reduces the energy self-sufficiency rate.

1. Electric Power Innovation Advancing Around the World

Renewable Energy Becomes Cheap and Dependable

Solar, wind, and other renewable energy sources are considered to have the lowest total lifetime cost of any electric power decarbonization technology (Fig. 1). Since they represent a domestic form of energy production, they are also less susceptible to fossil fuel price fluctuations, like the spike in natural gas prices precipitated by the invasion to Ukraine.

Fig. 1 Index of Competitiveness of Power Generation, Equipment, and Materials in Advanced Economies (2022; Existing Technology = 100)



Source: IEA (2024), *Strategies for Affordable and Fair Clean Energy Transitions*, IEA, Paris.

Explanation: The table shows the cost of various decarbonization technologies relative to the lifetime cost of a typical non-decarbonization technology (natural gas-fired power in the case of electricity), which is assigned a value of 100. The analysis for developed countries shows that **solar, onshore wind, and offshore wind all cost less than natural gas**.

Taking advantage of these lower costs, more and more countries are putting renewables at the center of their national strategies for electricity decarbonization. Germany, Italy, and Australia have respectively set themselves the goal of producing at least 80%, 72%, and 82% of their electricity from renewables by 2030. The U.S. and UK have not set targets for specific power sources, but they have committed to the goal of power decarbonization by 2035, with scenarios put forward by government agencies featuring renewables as the main source of decarbonized power. In its Net Zero Emissions by 2050 Scenario (NZE Scenario), the International Energy Agency (IEA) foresees renewable electricity accounting for 59% of total global electricity supply by 2030, and 89% by 2050.

Storage Batteries, Interconnections, and IT are Key to Innovation

As more countries are committing to generating the majority of their electricity from renewable sources, innovations in electric power systems are being generated all over the world. The key areas of innovation are storage batteries, power grids, and information technology (IT).

While batteries can store the surplus power that solar power systems generate during the day for use at night, high cost was a barrier to their utilization. The cost of storage batteries has fallen dramatically in recent years, however.[6] Although it was previously thought that inertia,[7] which is important for grid stability, could only be provided by rotating machines like those of thermal power generation systems, storage batteries are eligible to serve this function.[8] Furthermore, competition in the development of new battery technologies, such as sodium-ion batteries, made from less unevenly distributed resources, is intensifying.[9,10] The falling cost of storage batteries is driving innovations that are upending the conventional wisdom of electric power systems.

Enhancing interconnection grids also enables cross-regional interoperation. There is hardly a day in Japan when the wind does not blow or the sun does not shine anywhere in the country.[11] If power transmission lines are interconnected, various power sources, energy storage systems, and demand responses can be readily utilized.

The use of information technology (IT) has made it possible to predict the amount of electricity generated by solar and wind power with considerable accuracy, so demand is shifted to times of surplus generation in accordance with such supply predictions. Even the storage batteries of electrical vehicles (EVs) can contribute to grid stabilization if they draw power from the grid for recharging at times when electricity is cheap and supply power to the grid at times when insufficient power is generated (thereby earning money by selling power).

These power system innovations relating to storage batteries, power grids, and IT have overturned the conventional wisdom of power systems and energy (Table 1). While the cost of solar and wind power is low, as mentioned above, the falling cost of storage batteries is making renewable power more reliable than ever.

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[6] RMI (2023), *X-Change: Batteries, The Battery Domino Effect*

[7] Inertial energy refers to energy that suppresses the rate of frequency fluctuation in power systems when supply and demand vary over short periods of time or when large power sources drop out. Traditionally, frequency stability has been provided by the inertia of the rotating machines used in thermal power generation systems (analog inertial energy). (This is the physical property that such machines continue to rotate even after input energy is stopped.) Recently, however, it has become possible to provide this inertial energy using variable-speed wind power generators (which are also rotating machines) and storage batteries (digital inertial energy). Significant technological developments are also being made in combining rotating machines (synchronous regulators and flywheel generators) with storage batteries. (See Sousa (2024), *Hybrid grid stabilization with synchronous condenser (SynCon) and battery energy storage system (BESS)*).

[8] Tomas Kåberger (2024), *100% Renewable Electricity System in a 100% Renewable Energy System*, Energy & Resources Vol. 45, No. 2.

[9] Bloomberg (2023), *Sodium in Batteries: Shift May Herald Another Shakeup*

[10] By late 2023, Swedish lithium battery maker Northvolt and Chinese EV maker BYD had already concluded plans to develop sodium-ion battery products and build manufacturing plants (2023, Bloomberg).

[11] The analysis presented in the report *Renewable Pathways: The Strategies to 100% RE for a Carbon-neutral Japan published in 2021 [in Japanese*] by Renewable Energy Institute, which looked at solar and wind power generation across Japan in 2018 and 2019, found that combined solar and wind power output fell to 10% or less for up to 18 consecutive hours.

Table 1 The Conventional Wisdom of Electric Power Systems/Energy has been Overturned

	Conventional wisdom	Current situation
Cost of solar, wind and storage	High	Low
Variability of solar and wind power	Unreliable	Predictable. Reliable with storage and enhanced grid.
Demand for electricity	Static (cannot change)	Dynamic by prices and other factors
Inertia	Can only be provided with thermal power	Can be provided with wind power, storage batteries, andsynchronous phase modifier
Energy is …	Need to import from oversea	Can domestically produced
Battery materials	Made from resources available only in limited locations, e.g., China	Can be made from widely available resources, e.g. salt for sodium-ion batteries

Source: Renewable Energy Institute

And Japan still has much untapped potential for renewable energy. As yet, only about 10% of homes in Japan are equipped with solar power. Installing solar power systems on unused farmland can help farmers to increase their income. And according to the IEA, offshore wind power alone has the potential to produce eight times the total electricity demand of Japan.[12]

[12] IEA (2019), *Offshore Wind Outlook 2019* (IEA, Paris)

2. Simulation: 65% CO_2 Reduction, 80% Renewables Electricity in FY2035

This analysis describes a vision of how Japan can achieve 80% renewable electricity and a 65% reduction in CO_2 emissions by FY2035 (relative to FY2019) by taking advantage of power system innovations that are spreading throughout the world.[13]

Fig. 2 Analytical Framework: To Show One Consistent Future with 65% CO_2 Reduction

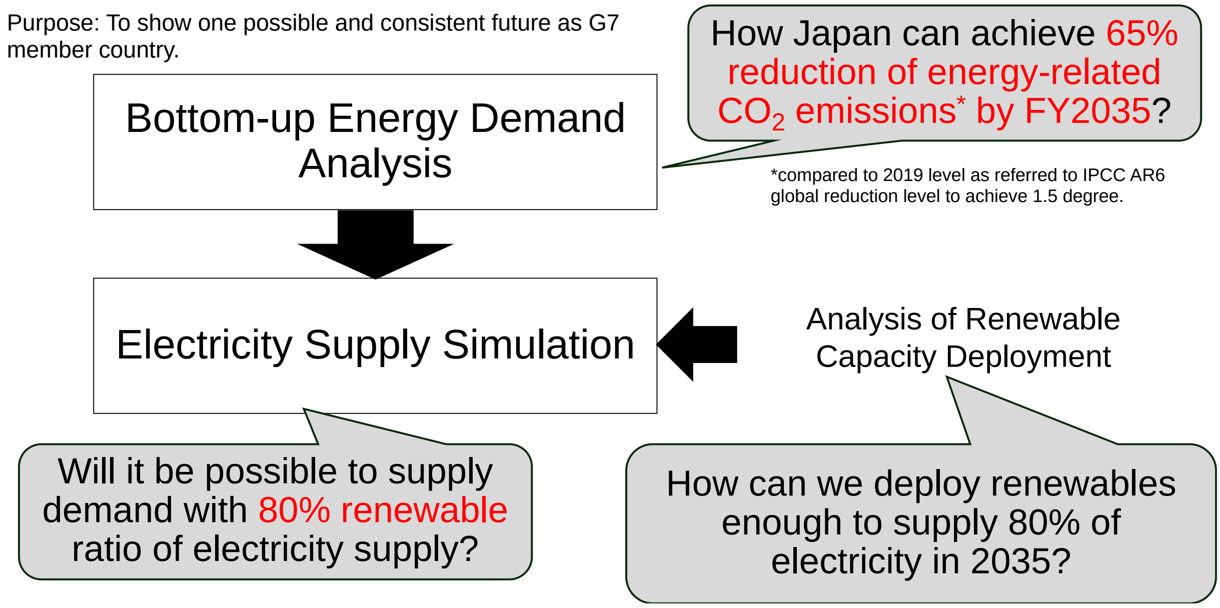

Fig. 2 shows the framework of this analysis. In our analysis, we calculated energy demand assuming the measures needed to fulfill Japan's international responsibility to cut CO_2 emissions by at least 65% (relative to FY2019) by FY2035 are taken. After demand for all types of energy demand is determined, we ran simulation how to fulfill electricity demand by 80% renewable sources, assuming possible renewable capacity deployment.

To ensure the analysis is as realistic as possible, we did not use a cost minimization method for capacity expansion. This is because the results of such a method are heavily influenced by the cost estimation of each technology.[14] Instead, utilizing our expertise, we set out to clarify in detail what and how much can be done, by specifying realistic maximum efforts based on trends for each technology, standards, and regulations.

Fig. 3 summarizes the analytical framework in more detail.

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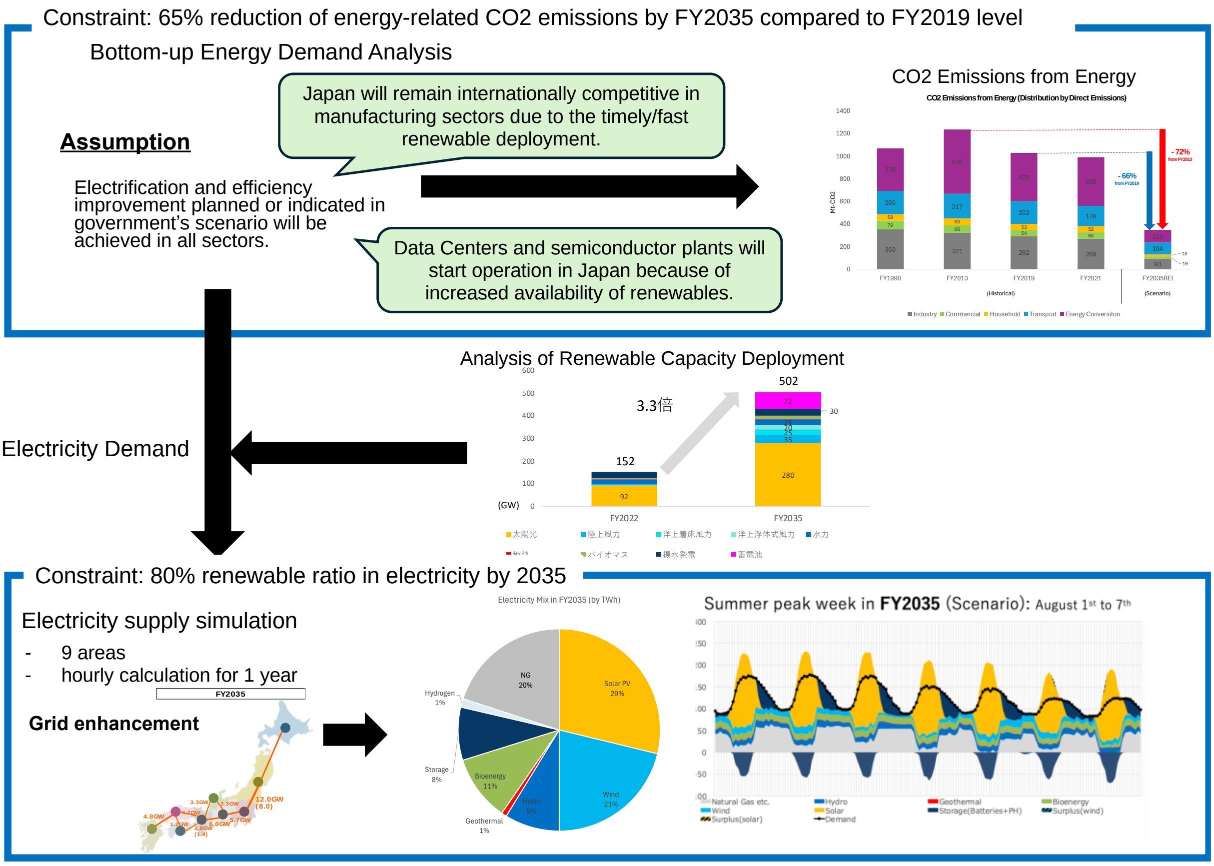
[13] As a result of the limitations of the software used for this simulation, we assumed only a limited level of demand response due to the increased use of IT. Although this is topic for further study, it is clear that the use of demand response will make the integration of renewables significantly easier.

[14] Even for the same cost at the time of deployment, the setting values input as model assumptions differ significantly according to the discount rate and payback period settings. In cost minimization computations, the cost assumptions have a substantial impact on the results, because the supply structure is computed by determining the lowest cost when all constraints are satisfied.

Fig. 3 Analytical Framework (Detailed)



The steps of the analysis are explained below.

2-1. Energy Analysis: How Can Japan Achieve 65% CO_2 Reduction by 2035?

The Sixth Assessment Report of the IPCC shows that **a 60% reduction in global greenhouse gas and 65% reduction in global CO_2 emissions by 2035 (relative to 2019) are needed** to limit the average temperature increase from pre-industrial revolution level to 1.5°C with a probability of at least 50% [IPCC, 2023].[15]

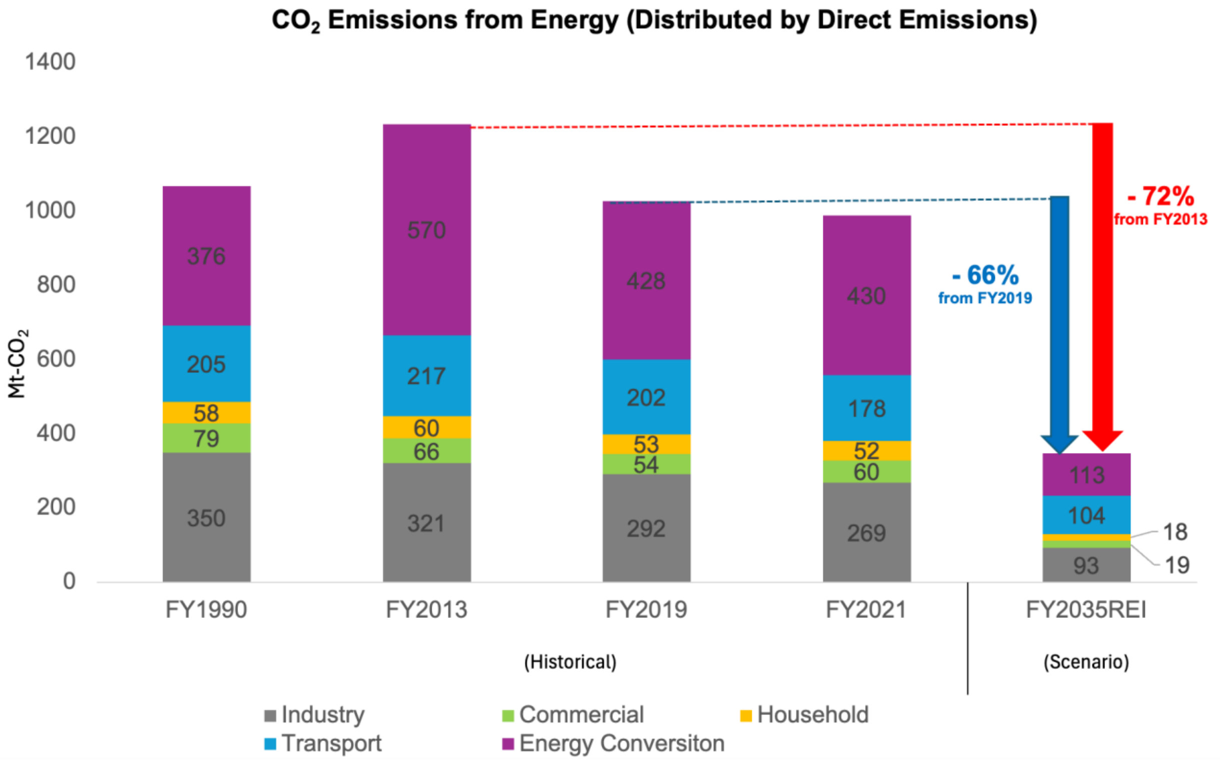
In this analysis, the IPCC envisions the required 65% CO_2 reduction by 2035 (relative to 2019) as worldwide. This scenario, which features the deployment of a large quantity of renewable energy, will (1) enable the decarbonization of domestic manufacturing, including steel production; (2) attract data centers and semiconductor plants that must operate on renewable energy to Japan; and (3) generate new demand for offshore wind power and power transmission lines. As a result of these three effects, Japan will be able to preserve its domestic industrial base, i.e., avoid an industrial hollowing-out.[16]

[15] IEA (2023), *Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach*, states that to keep global temperature rise to within 1.5°C, developed countries will need to reduce their total greenhouse gas emissions by 80% by 2035 (relative to 2022), compared to 60% for developing countries and other countries. A next level of reduction beyond a 65% reduction in CO_2 emissions, the responsibility of developed countries, needs to be considered, including transformation of industrial structure.

[16] Specifically, it was assumed that the 2030 activity level assumed in the relevant document of the 6th Basic Energy Plan, *Outlook for Energy Supply and Demand in FY2030* (2021) [in Japanese], would be maintained. The 6th Basic Energy Plan assumes a real GDP growth rate of 1.7%/year.

Additionally, by means of strategic electrification and aggressive efficiency improvements, e.g., by shifting from blast furnaces to electric furnaces in steel production (increasing from current level of 26% to 45%), it is possible to calculate CO_2 emissions in FY2035 to be 66% below the FY2019 level (Fig. 4). (See Table 2 for details.)

Fig. 4 Energy-related CO_2 Emissions: Actual Versus Scenario (Direct Emissions by Sector, Mt-CO_2)



Source: Actual: Comprehensive Energy Statistics, Ministry of Economy, Trade and Industry; FY2035: simulation results

Explanation: This simulation demonstrates the feasibility of a 72% reduction relative to FY2013 and a 66% reduction relative to FY2019 (65% relative to FY2021).

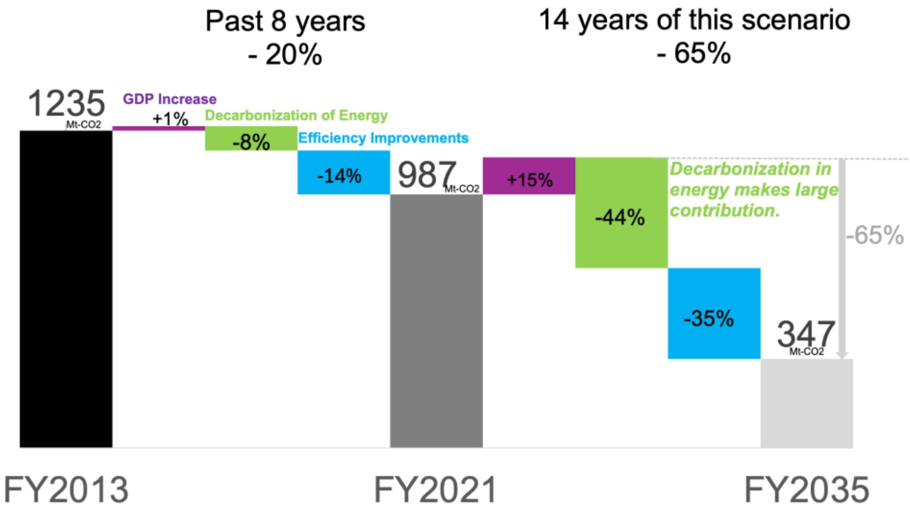
Table 2 Electrification and Efficiency Improvement Assumptions by Sector

Sector		Assumed electrification	Assumed efficiency improvement
Industry	General industry	Advances in low-temperature heat use for production and air conditioning (electrification rate: 20%) Electrification of moderate temperature heat use for production is growing in the non-materials manufacturing industry (electrification rate: 20%).	Achievement of Energy Efficiency Act benchmarks or equivalent efficiency improvement rate
	Steel industry	Strategic electrification in the steel industry (electric furnace rate up from 26% to 45%)	
Commercial		Progress in renewal and increasing the efficiency of facilities and equipment in line with the ZEB[17] conversion schedule of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) (32% compliance to energy efficiency standards, 36% or better compliance to guidance standards)	
Household		Progress in renewal and increasing the efficiency of facilities and equipment in line with the ZEH[18] conversion schedule of MLIT (16% compliance to energy efficiency standards, 27% or better compliance to guidance standards).	
Transportation	Passenger	15% of passenger cars are EVs (stock)	2030 fuel efficiency standards (passenger cars), ICAO targets (aviation), and IMO targets (cargo ships) are all achieved.
	Freight	10% of trucks are EVs (stock)	

[17] ZEB = (Net) Zero Energy Building
[18] ZEH = (Net) Zero Energy House

Note that 44% worth of this 66% reduction will be achieved through energy source decarbonization (Fig. 5). This is due to both the switch from fossil fuels to electricity and the fact that 80% of electricity is produced from renewables.

Fig. 5 Percentage of Emissions Reduction from Energy Decarbonization and Efficiency Improvement



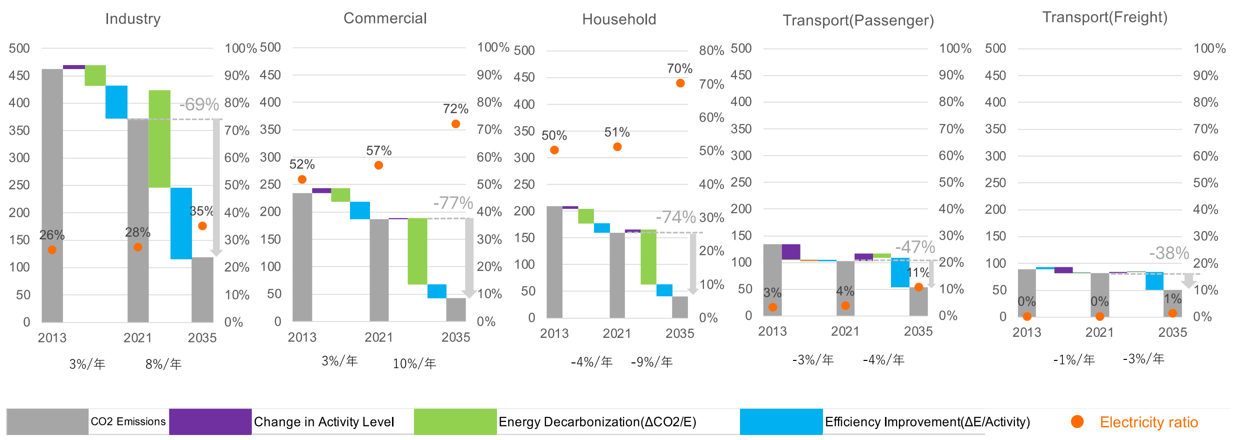
Explanation: In the eight years from FY2013 to FY2021, CO_2 emissions fell by 20%. The contribution of energy efficiency to this reduction (14% out of 20%) was far more than that of energy decarbonization. In our scenario, substantial progress in electricity decarbonization makes a large contribution (44%) to the 65% reduction in CO_2 emissions by FY2035.

The agreement that concluded at the 28th Conference of the Parties to the UN Framework Convention on Climate Change (COP28) held in Dubai in late 2023 incorporated a commitment to tripling installed renewable energy capacity and doubling the energy efficiency improvement rate by 2030. Under our scenario, Japan's energy efficiency improvement rate will increase from 1.9% (2013–2021) to 4.1% per year. In other words, it will double, in line with the COP28 commitment.[19]

By sector, the reductions between FY2021 and FY2035 are 69% for industry, 77% for commercial sector, 74% for households, 47% for passenger transportation, and 38% for freight transportation (Fig. 6). Looking at the reductions (length of gray arrows) rather than the percentage figures makes it clear that reduction in the industry sector is very significant.

[19] The analysis used the Kaya identity (CO_2=CO_2/E*E/GDP*GDP). See Y. Kaya (1990), *Impact of Carbon Dioxide Emission Control on GNP Growth: Interpretation of Proposed Scenarios*, *IPCC Energy and Industry Subgroup, Response Strategies Working Group.* Our analysis was performed logarithmically without cross terms.

Fig. 6 Factor Analysis of CO_2 Reduction, and Electrification Rates (Mt-CO_2, %) by Sector: Past Versus Scenario



Explanation: For each sector, for both past and scenario periods, we analyzed whether reductions occurred as a result of energy decarbonization (green) or energy efficiency improvement in the economy (blue). Since the scale of the vertical axis is the same for all sectors, it's easy to see that the scenario results in large reductions in the industry, commercial and household sectors. Although the reduction rate in transportation is relatively large, some activities, such as long-distance transportation, are difficult to electrify, therefore resulted in small amount of reduction. In the future, these activities could be powered by domestic green hydrogen, which should be available in abundance from renewable electric power generation systems.

Decarbonization of the steel sector, which accounts for approximately 40% of all CO_2 emissions from industry, contributes significantly to the reduction in this sector. However, simply converting to electric furnaces will not result in massive CO_2 reductions. Emissions will be significantly reduced because 80% of the electricity used to power converted furnaces will come from renewable energy sources.[20]

In addition to reducing emissions, the shift to electric furnaces in steel production will also contribute to improve the stability of Japan's electricity supply, as well as generate a new source of income through demand response. This means that steel mills would operate less when electricity prices are high (when there is a shortfall in electric power output) and more when prices are low, or even negative.

Steel and cement are essential for the development of infrastructure such as wind power and transmission grids. If renewable energy-related facilities and power grids are sufficiently enhanced, it will help to attract data centers and semiconductor plants.[21] Like this, a virtuous cycle of renewable energy deployment and economic revitalization will develop.

If the deployment of renewable energy accelerates even further, from 2035 it will also be possible to produce hydrogen and syngas domestically. This will be vital for decarbonizing activities that cannot be efficiently decarbonized through electrification, like long-distance transportation and high-temperature heat.

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[20] As well as scrap iron, reduced iron can be used for electric furnaces. Some countries that have already deployed renewables in large quantity, like Australia, have plans to make use of domestic green hydrogen to produce and export reduced iron.

[21] This analysis assumes that the increased deployment of renewables will attract data centers, semiconductor plants, and other facilities. Consequently, although electricity demand will grow, the increase in electricity consumption due to the attraction of data centers is estimated to be only 10 TWh (slightly over 1% of FY2022 electricity demand), thanks to ongoing efficiency improvements.

Column: AI will Drive up Electricity Demand, but also Boost Energy Efficiency, so Renewables are Vital for Attracting Data Centers and Semiconductor Plants

AI training (machine learning) requires huge amounts of power, labor, and data stock. Much of this AI training is being done by U.S.-based big tech companies.[22] In fact, the "big five" (GAFAM) and other major U.S. tech companies along with semiconductor makers such as Intel are either members of RE100 or else have made commitments to similar goals.[23] Since these U.S. tech companies are striving to achieve 100% renewables as early as before 2025, to enable them to locate large AI servers in Japan, they will need to have access to large quantities of inexpensive renewable energy as soon as possible.

Of course, electricity is also necessary for services that utilize trained AI. In an automated share trading system, for example, a delay of less than one second can be disastrous, so servers need to be located close to users. For this reason, U.S. tech firms have recently been locating their servers in metropolitan areas of Japan. However, some of these have voiced concerns about the difficulty of procuring renewable energy in Japan. For applications in which computational speed as high as one second is not critical, it is reasonable to presume that tech companies will seek to locate servers in areas where renewable energy can be sourced cheaply, as in the case of AI training. In other words, the question of **how quickly and inexpensively large quantities of renewable energy can be secured will significantly influence the location of servers**.

The IEA estimates that worldwide electricity demand for data centers and the like, including those where generative AI is trained and used, will nearly double between 2022 and 2026, to around to 1,000 TWh.[24] This is equivalent to a 2% increase in global electricity consumption in 2022. According to an estimate by the Central Research Institute of Electric Power Industry (Japan), additional electricity demand for data centers, etc. in 2050 will amount to somewhere **between 2% and 20% of Japan's total electricity demand**.[25] It should be noted that while this increase is a significant quantity, it is nowhere near a doubling or tripling of national electricity demand.

It has also been pointed out that **the use of AI and other kinds of IT will make it possible to accurately predict, manage, and operate distributed facilities such as renewable power systems and storage batteries, as well as electric power demand, resulting in significant efficiency gains**.[26] This is truly a transition to a new power system. Amory Lovins, founder of the Rocky Mountain Institute, has pointed out that by 2040, energy production could become three times more efficient[27], which will be made possible by IT. Advances in the use of AI are likely to facilitate the substantial utilization of renewable energy, leading to "deep efficiency." At the same time, demand response, e.g., shifting non-urgent computation to times of surplus power generation, which is already being done,[28] will also contribute to grid stability. Thus, in the age of AI, the utilization and efficiency of renewable energy will rise further.

The question of **how many servers and semiconductor plants will be located in Japan is likely to depend on how quickly and massively inexpensive renewable energy can be deployed**.

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[22] Nestor Maslej, Loredana Fattorini, Raymond Perrault, Vanessa Parli, Anka Reuel, Erik Brynjolfsson, John Etchemendy, Katrina Ligett, Terah Lyons, James Manyika, Juan Carlos Niebles, Yoav Shoham, Russell Wald, and Jack Clark, *Artificial Intelligence Index Report 2024*, Institute for Human-Centered Artificial Intelligence, Stanford University, April 2024. According to this report, of the leading AI models in 2023, 61 were from U.S., 21 from EU and 16 from Chinese institutions.

[23] Of the five major big tech (GAFAM) U.S. companies, Google, Apple, Meta, and Microsoft are all RE100 members, respectively committing to 100% renewables by 2017, 2021, 2020 and 2014. Amazon has committed to using 100% renewable electricity for its operations by 2025. Of the major semiconductor makers, Intel, TSMC, Samsung SDI, and Advantest have all committed to operate on 100% renewables by 2030, 2040, 2050, and 2050, respectively, through participation in the RE100 initiative. Keoxia has committed to 100% renewables by 2040.

[24] IEA (2024), *Electricity 2024* (IEA, Paris)

[25] Central Research Institute of Electric Power Industry (2024), *Long-term Electricity Demand Assumptions for the Whole Country to 2050: Tentative Estimation Results for Additional Factors (Changes in Industrial Structure)[in Japanese]*

[26] IEA (2023), *Why AI and energy are the new power couple* (IEA, Paris)

[27] Amory B. Lovins (2018), *How big is the energy efficiency resource?* Environ. Res. Lett. 13 090401

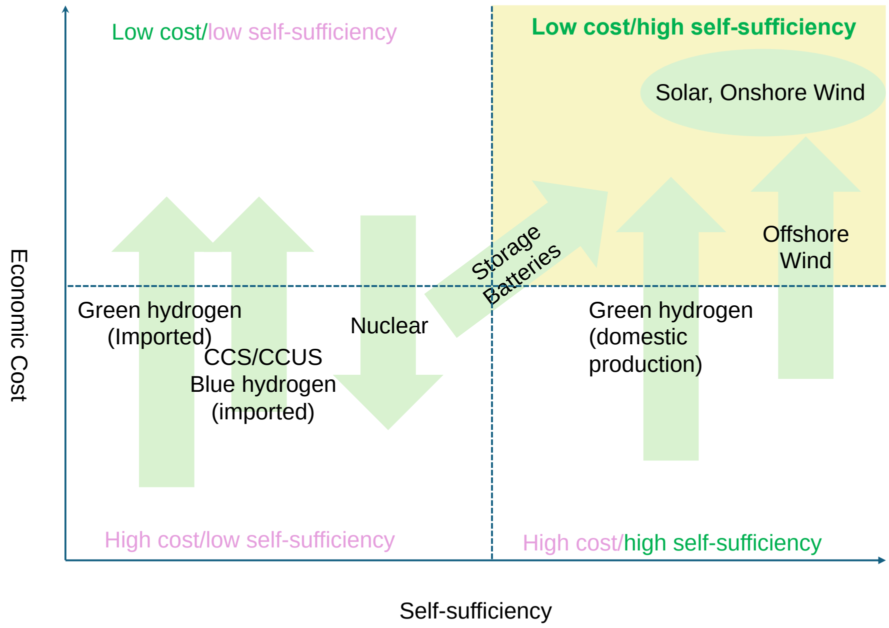
[28] Google (2023), *Supporting power grids with demand response at Google data centers*

Column: Domestically Produced Energy is the Best Form of Energy Security

The **early adoption of renewable energy** in Japan will drive up energy self-sufficiency, both in the medium and long term. **In the medium term, domestically produced energy will be limited largely to the electric power sector**, but **in the long term, non-electric forms of domestically produced energy will also expand**.

Fig. 7 maps the self-sufficiency and economic cost of typical decarbonization technologies.[29] The green arrows indicate current trends and possibilities. The yellow area at the top right indicates both low cost and high self-sufficiency.

Fig. 7 Mapping of Self-Sufficiency and Economic Cost of Decarbonization Technologies



Explanation: Decarbonization technologies vary not only in cost, but also terms of their energy security value, according to whether they rely on domestically produced or imported resources. The ideal is to have a mix with as much inexpensive, domestically produced energy (top right) as possible.

The decarbonization technologies that are trending toward the top right of the map are both economically viable and self-sufficient, or at least have the potential to become so. Solar and onshore wind are already highly economical, as well as being desirable in terms of self-sufficiency. In contrast, CCS/CCUS will not reduce dependence on imported fuels. Worse still is the idea of exporting CO_2 emissions to Southeast Asia, which has been discussed, because it would lead to a sort of double foreign dependence. Although the Japanese government classifies nuclear power as a “quasi-domestic energy source,” the degree of self-sufficiency is actually a little below the middle, because uranium needs to be imported. According to Fig. 1, the IEA,[30] and the U.S. Department of Energy,[31] the cost of nuclear power is higher than that of gas-fired power.[32]

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[29] Gray hydrogen (made from fossil fuel) is not included in decarbonization technologies. Blue hydrogen is included as CCS.
[30] IEA (2020), *Job creation per million dollars of capital investment in power generation technologies and average CO_2 abatement costs* (IEA, Paris)
[31] U.S. Energy Information Administration (DOE), *Levelized Costs of New Generation Resources in the Annual Energy Outlook 2022*
[32] In the case of Japan, the cost of restarting nuclear power plants is likely to be quite different to that in other countries, because many of the nuclear power plants that were in operation were shut down in the wake of the Fukushima nuclear accident. If the restarts and extensions of operation already approved as of June 2024 are considered, the amount of electricity generated from nuclear power generation in FY2035 is estimated to be 48.7 TWh, which amounts to about 5% of the total electricity generated in FY2035 (based on a plant capacity factor of 70%). Assuming that all current applications to restart or extend the operation of plants are granted (and a plant capacity factor of 70%), the quantity of nuclear electricity generated in FY2035 is estimated to be 109.1 TWh, amounting to around 11% of total electricity in FY2035.

In the case of hydrogen, the production cost of transportation and storage is high,[33] so importing hydrogen is expected to be relatively expensive,[34] even if the cost of both green and gray hydrogen has been dropping. And importing hydrogen will naturally lead to lower self-sufficiency.

The cost of storage batteries is falling sharply. Additionally, for certain types of batteries, it may be possible to eliminate dependence on unevenly distributed resources, thereby increasing self-sufficiency. Thus, in this case too, the trend is toward the top right.

Renewable energy is a domestic energy source that flows all across the country whenever there is sunlight. As soon as possible, Japan needs to start focusing its **limited financial, time, and policy resources** on energy efficiency and renewables. This is vital for realizing **an inexpensive and resilient energy system that is not dependent on foreign suppliers**.

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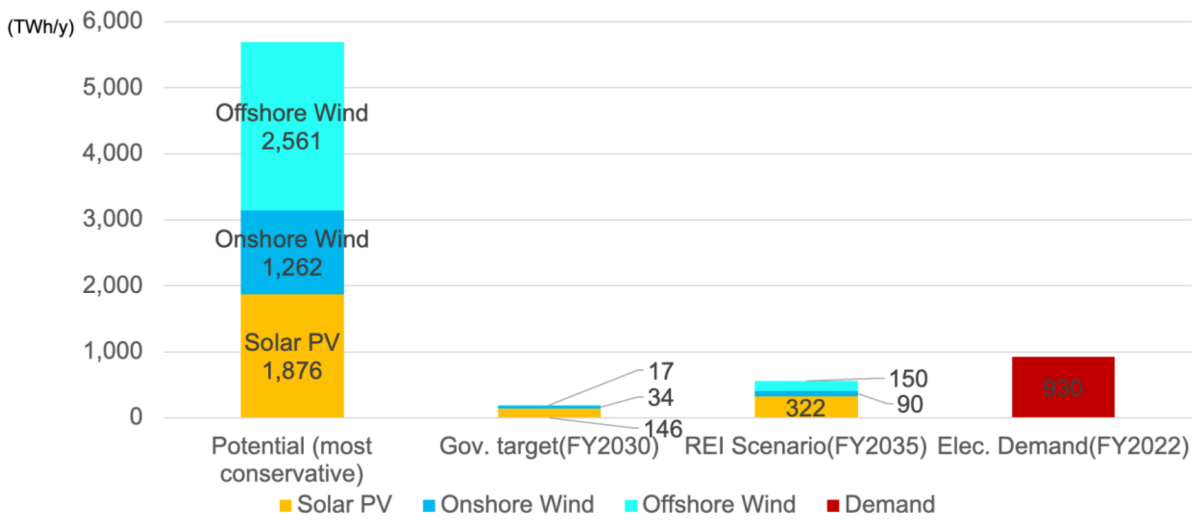
[33] IEA (2023), *Global Hydrogen Review 2023* (IEA, Paris)
[34] Assuming that renewables are massively deployed in Japan and that domestically produced green hydrogen is produced during times of low and negative electricity prices.

2-2. Renewables Potentials in Japan

Japan is blessed with an abundance of renewable energy resources. These are **domestically produced energy** sources. Once solar and wind power systems are installed, there are **no fuel costs, or impacts of price fluctuations arising from international circumstances**. The installation and maintenance of these power systems can also generate local employment.[35] Renewable energy resources are widely available throughout the country. Monetization of these resources and job creation in the areas around these power systems can help to **revitalize regional Japan**.[36]

From the survey results estimating the potential of renewable energy in Japan, we adopted the lowest value for each category and compared it with the government targets ("ambitious" 2030 scenario of the 6th Basic Energy Plan), the 2035 scenario presented in this report, and actual electricity demand in FY2022 (Fig. 8).

Fig. 8 Japan's Minimum Total Renewable Energy Potential is More than Six Times Higher than Annual Electricity Consumption[37]



Explanation: According to even the most conservative estimates, solar and wind power alone have the potential to supply six times more than the total electricity demand (shown in red on the right).

Sources: For solar power, Ministry of the Environment; for onshore wind power, Renewable Energy Institute taking into account wind speed limitations, based on the Ministry of the Environment; for offshore wind power, Renewable Energy Institute. These are the most conservative of all the available power generation estimates by the IEA, the Japan Photovoltaic Energy Association, the World Bank, Mitsubishi Research Institute, and other sources.

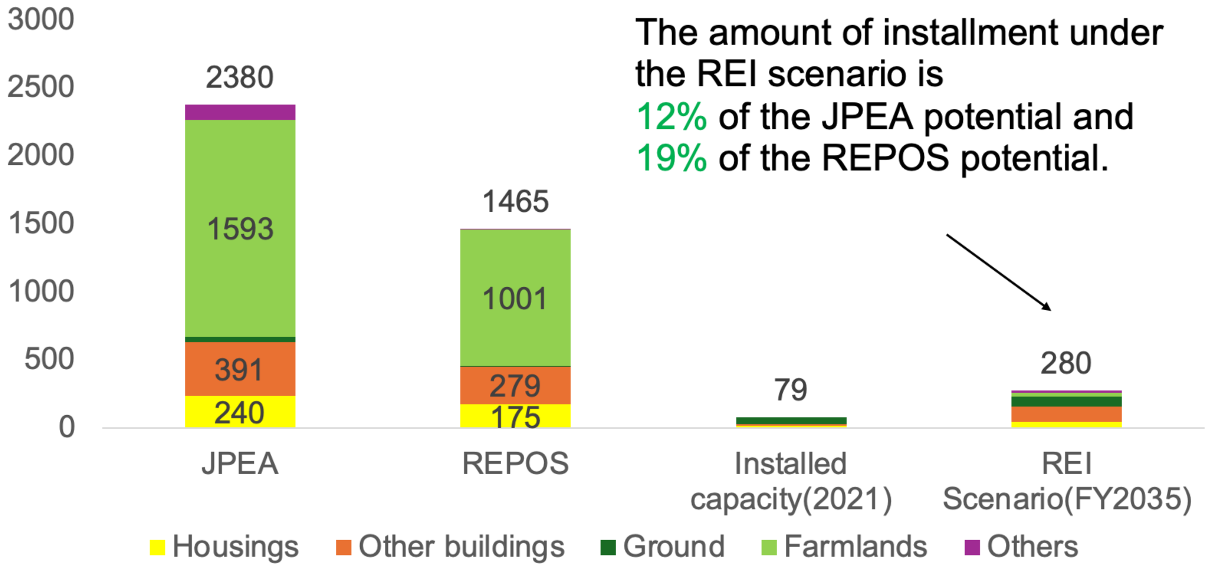
Fig. 8 shows that even using these most conservative estimates, Japan has **the potential to produce six times more electricity from renewable sources than its total electricity demand**.

[35] There needs to be a mechanism to ensure that local jobs are created.
[36] Kenji Inagaki (2022), *New Regional Electricity: Urban Development to Earn Money from Decarbonization*
[37] For various estimates of solar and wind potential, see the full version of this scenario. The minimum values on a TWh basis are taken from these estimates. The estimates for offshore wind power are based on a limit of 200 m for water depth, but recently there are reports that offshore wind power can realistically be implanted at greater depths. (See Mariko Furukawa, Saki Tomita, Yusuke Kakinuma (2024), "Current Status and Challenges for Early Mass Installation of Offshore Wind Energy," in *Energy & Resources* Vol. 45, No. 2); REI (FY2035) are the values of the model calculations used in this study, which do not include supply and demand in the Okinawa area, which amounts to approximately 1%. Note that Ministry of Environment documents [in Japanese] refer to solar power potential on an AC (alternating current, power conditioner output) basis.

It is sometimes argued it is difficult to install more solar power systems in Japan as the nation has a small land area and the rate of solar power system installation per land area is already high.[38] However, as of 2022, the proportion of homes with solar power was just 6.6% (12% for detached houses)[39], so there is still plenty of room for growth. In addition to residential buildings, both the Ministry of the Environment[40] and the Japan Photovoltaic Energy Association[41] see substantial potential for solar on farmland, including unused and degraded farmland (Fig. 9).

For details about the how and where solar power capacity can be deployed by 2035 as in this scenario, please refer to *Proposal for the 2035 Energy Mix* (First Edition) published by the Institute in April 2023. For example, the proposed installation rate for new homes is 80% in 2030 and 95% in 2035. It also included efficiency improvements in the future, therefore the capacity that can be installed by area will also increase.

Fig. 9 Estimated Solar Power Potential and Installed Capacity (GW^{DC}): Current Versus Scenario



Explanation: JPEA and the Ministry of Environment (REPOS) also see a very large potential in farmland. The assumed installation capacity for this simulation is shown on the far right.

Sources: For potential, JPEA and Ministry of the Environment; for current (already installed capacity in 2021), *Proposal for the 2035 Energy Mix (First Edition)* by Renewable Energy Institute (April 2023).

As for wind power generation, Japan is described as having a relatively small area of shallow seas and no places where the prevailing westerly winds blow continuously. However, the development of floating offshore wind power, which is now on the horizon, has significantly boosted Japan's wind power generation potential.

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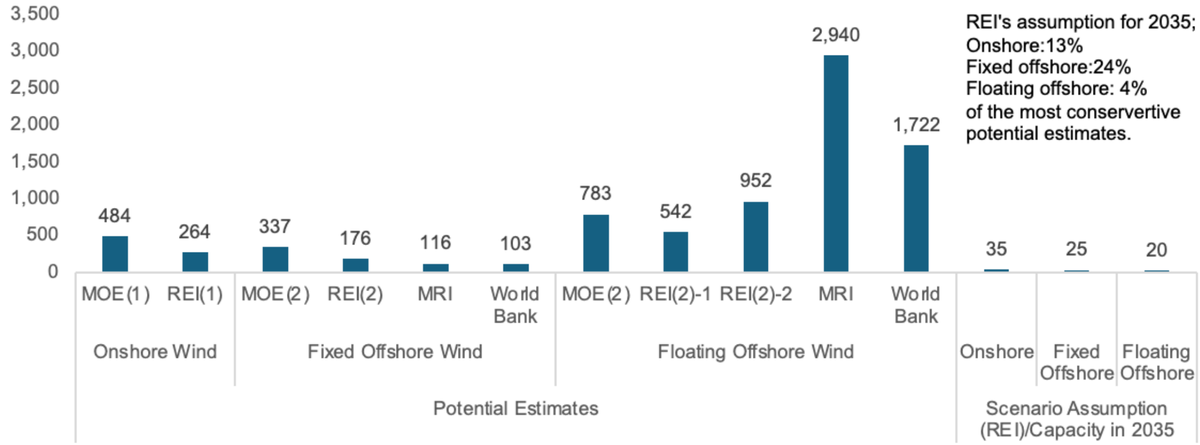
[38] Agency for Natural Resources and Energy (2022), Study Group on the Introduction and Management of Renewable Energy Generation Facilities
[39] Ministry of the Environment (2024), *Results of 2022 Statistical Survey on Household Sector CO_2 Emissions (Confirmed Report)[in Japanese]*
[40] Ministry of the Environment (2022), *Entrusted Work to Examine Measures to Use and Provide Information Concerning the Introduction Potential of Renewable Energies in FY 2021*
[41] Japan Photovoltaic Energy Association (2024), *PV OUTLOOK 2050: A New Vision for the Solar Power Industry* (tentative 2023 version)

In this scenario, the installed capacity up to 2035 was estimated in line with the approach outlined in *Proposal for the 2035 Energy Mix (First Edition)* (REI, April 2023). The projection of offshore wind was made based on *Japan's Offshore Wind Power Potential: Territorial Sea and Exclusive Economic Zone* (REI, November 2023). More specifically, we set an installed capacity for the end date in each region by setting upper limit for the development rate and the installed capacity, based on the onshore and offshore wind power potential for each area. We then applied logistic curve from current installed level to the end date level to calculate 2035 installed capacity.

Fig. 10 Estimated Wind Power Potential and Installed Capacity in This Scenario (GW)



Explanation: Estimates of the potential for floating offshore wind power are typically very high. In comparison, the estimates of the Renewable Energy Institute (REI) in all types are quite conservative.

Sources: Ministry of the Environment (1): Entrusted Work to Examine Measures to Use and Provide Information Concerning the Introduction Potential of Renewable Energies in FY 2021 (April 2022); and (2): *Entrusted Work Concerning the Development and Disclosure of Basic Zoning Information Concerning Renewable Energies (FY 2019)* (March 2020). Renewable Energy Institute (1) *Proposal for the 2035 Energy Mix (First Edition)* (April 2023); and (2): *Japan's Offshore Wind Power Potential: Territorial Sea and Exclusive Economic Zone* (November 2023). Mitsubishi Research Institute: *Potential Sea Areas for Offshore Wind in Japan* (April 2024). IEA: *Offshore Wind Outlook 2019* (November 2019). World Bank: *Global Offshore Wind Technical Potential* (January 2023).

2-3. 80% Renewables Electricity System in 2035

We simulated an electricity supply structure that satisfies electricity demand based on incremental calculation of energy demand. The key question we posed was, "**Can a variable renewable energy-based electricity supply really meet demand?**" Using power generation data reflecting the annual weather pattern of Japan with hour-level granularity, we examined whether hourly demand could be met in each of nine regions of Japan.

For our simulation, we made use of Hitachi Energy's PROMOD,[42] the same modeling system used by the Organization for Cross-regional Coordination of Transmission Operators (OCCTO) in its master plan simulation for cross-regional interconnection grids. We took into account hourly supply and demand in each of the nine areas, interconnections between areas, and the securing of sufficient balancing power to enable grid stability. The results confirm that **80% renewable electricity is feasible by FY2035**. However, in addition to renewable energy systems, achieving this goal will require a substantial quantity of storage battery capacity and significant enhancement of cross-regional interconnections.

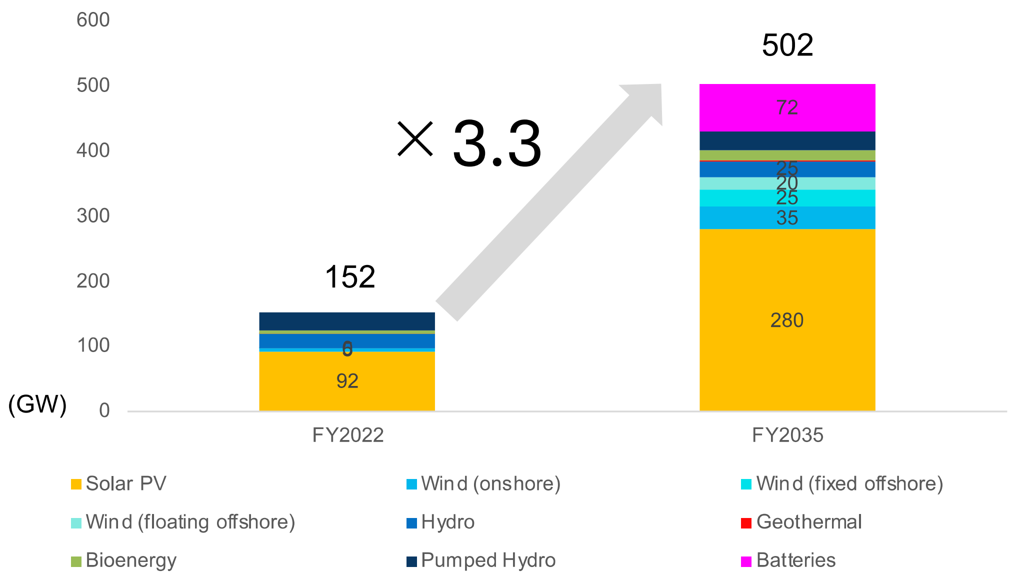
[42] This analysis was carried out in collaboration with Associate Professor Tatsuya Wakeyama, Tokyo Institute of Technology (Senior Research Fellow, Renewable Energy Institute). The supply-demand balance in the Okinawa region amounts to approximately 1% of the total supply-demand balance in Japan. Since Okinawa is not connected to Japan's electricity system, it was not included in our simulation.

Required Capacity Expansion: 3.3 Times More Renewable Energy Capacity and More Interconnections than OCCTO Master Plan

How much installed capacity would be needed to supply 80% of electricity from renewables? Our scenario assumes approximately 3.3 times more installed renewable generation capacity (output basis) relative to FY2022, including substantial storage capacity (Fig. 11).

Solar power already accounts for a large share of Japan's renewable energy, but by FY2035 we project installed capacity to triple (relative to FY2022). Wind power, which has developed more slowly than solar in the past, is projected to reach 80 GW of installed capacity by FY2035, in line with advances in both onshore and offshore wind power technology. On top of the storage offered by EVs[43] while not in use, we foresee a massive expansion in storage capacity, including grid-side storage, with total storage battery capacity estimated to reach 72 GW/184 GWh. **The combination** of large-scale deployments **of solar power and storage batteries will transform solar power into a predictable and reliable source of power.**

Fig. 11 Installed Renewable Power Generation and Storage Capacity (FY2022 and FY2035)[44]

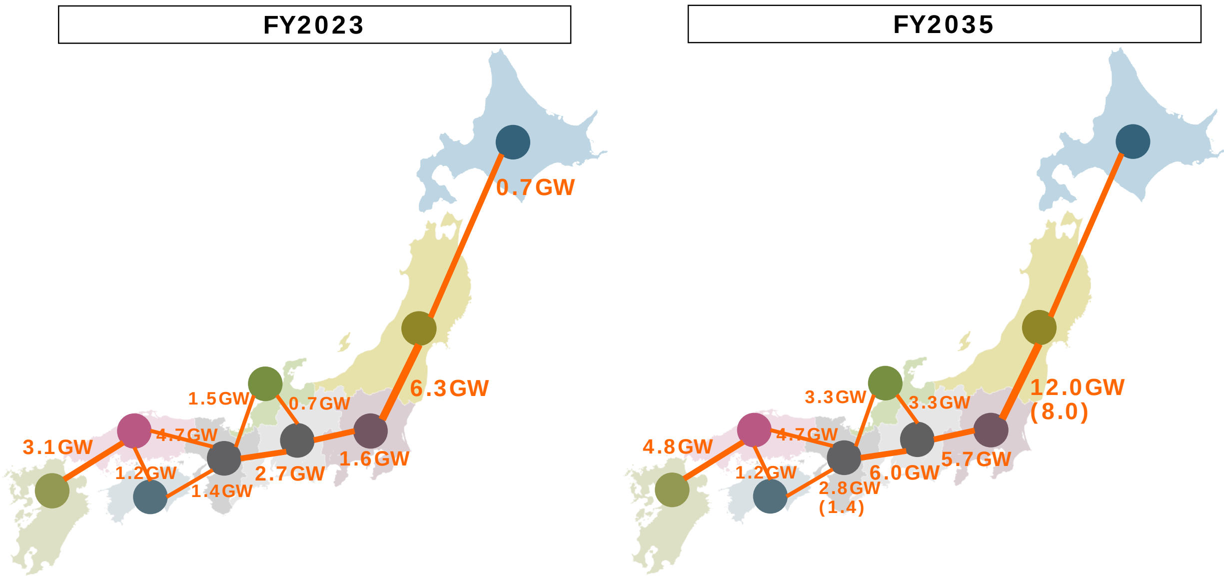


Explanation: We assumed that there will be 3.3 times more renewable power generation capacity in 2035 (relative to 2022) including storage capacity. Wind power appears to be insignificant in terms of installed power generation capacity, but offshore wind in particular, which boasts a high capacity factor, is expected to account for a large share of total renewable electricity, as shown in Fig. 14. Storage battery capacity is projected to increase to 72 GW/184 GWh.

What about grid interconnections? In accordance with the Institute's study in *2050: Decarbonizing Grid Systems with Renewables* (April 2023), we envision that by 2035 the interconnections between Hokkaido and Tokyo, and between Kansai and Shikoku will be enhanced well beyond the projected expansion based on the OCCTO Master Plan.[45]

[43] It was assumed (on a stock basis) that 15% of passenger cars and 10% of trucks are EVs, and that 15% of that total EV batter capacity is used as storage.
[44] For FY2022, the capacity is the value as of March 31, 2023 (end of the fiscal year). To enable comparison, solar power figures were also converted from AC to DC basis by multiplying by a factor of 1.3.
[45] Projects that have been studied in the Cross-regional Network Development Plan (of OCCTO) and that are likely to be constructed within approximately 10 years are included.

Fig. 12 Cross-Regional Power Grid Interconnections (Current Versus Scenario)

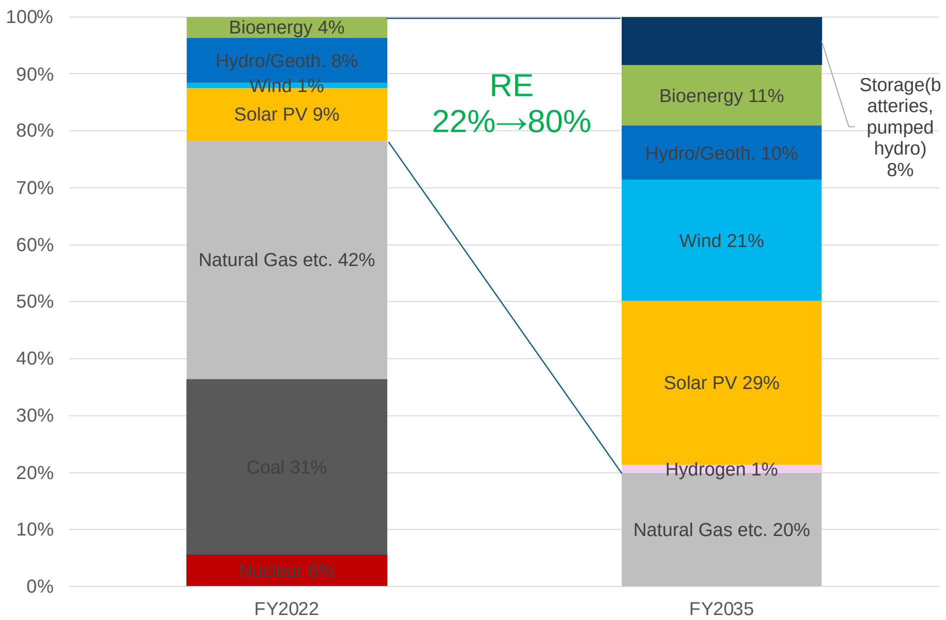


The figures in parentheses are based on the OCCTO Master Plan and include projects that are under consideration in the Regional System Improvement Plan and are expected to be constructed within approximately 10 years.

Simulation Results: Vision of an 80% Renewable Energy Power System

Fig. 13 shows the power supply structure resulting from our hourly simulation for one year. Solar and wind power account for 50% of total electricity. Demand supplied by storage batteries (including pumped storage) is 8%. It is assumed that coal-fired thermal and nuclear power are completely phased out, with no new construction of natural gas-fired thermal power.

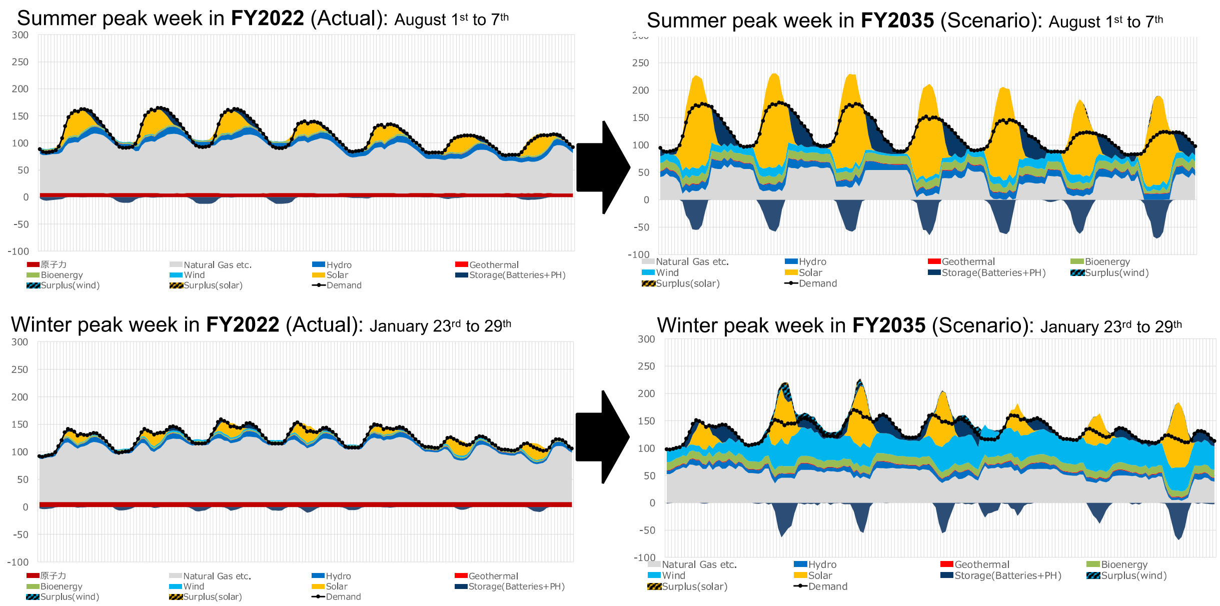
Fig. 13 Simulation Results for Electricity Supply Structure in 2035



How will power be supplied on an hourly basis?

Fig. 14 shows, both for FY2022 and FY2035, the hourly power supply and demand variation for all of Japan for two weeks of the year; the week that includes the summer demand peak on August 2 (weekday) and the week that includes the winter demand peak on January 25 (weekday).

Fig. 14 Hourly Supply Pattern: Electricity Supply and Demand for Week of Peak Summer Demand and Week of Peak Winter Demand (Left: Actual FY2022; Right: Simulation FY2035) (Vertical Axis: GW; Horizontal Axis: Hour)



Firstly, consider the week that includes the summer peak demand (top of Fig. 14). In FY2022 fossil fuels supply the majority of the base load. In FY2035, with 280 GW of solar power capacity, **the quantity of electricity generated during the daytime greatly exceeds demand**. **The surplus is stored for use in the evening and nighttime**. What about the winter peak (bottom of Fig. 14)? Whereas there is almost no wind power in FY2022, in 2035, with 80 GW of wind capacity, electricity generated will increase greatly. Since **wind systems can generate power at night**, there are many days when storage capacity is not utilized as much as in summer.

The big difference between FY2022 and FY2035 is not only the amount of renewable energy generated, but also the scale of storage and method of operation. In FY2022, electricity is stored at night, whereas in FY2035, virtually all electricity stored is the surplus solar power produced in the daytime.

Note that although dynamic pricing was not incorporated into the assumptions of our scenario, if we assumed dynamic pricing, we would expect demand to move more in line with the output of renewables; that is, with natural rhythms of the sun and wind. The question of dynamic pricing is a subject for future research.[46]

[46] The issue with PROMOD is that the relative scale of computations involving changes in demand, e.g., demand response, does not allow for solutions.

Column: Storage Batteries are a Game Changer

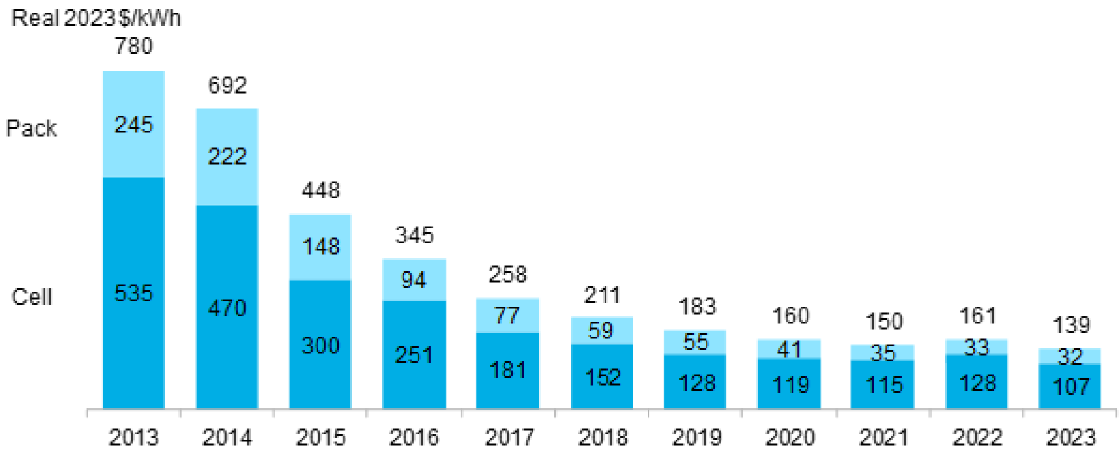
The cost of storage batteries is falling dramatically. Fig. 15 shows the weighted average unit price of storage batteries per kWh, including EV batteries. As of 2023, the price of battery packs is reported to have fallen below $139/kWh (¥20,000/kWh[47]). ($ = USD, ¥ = JPY)

Various countries around the world are also developing **batteries that do not rely on scarce resources such as lithium**, e.g., sodium ion batteries. Some reports suggest that the cell price of sodium ion batteries will fall to as low as $40–80/kWh.[48] If this kind of technology is widely available, it will be possible **to store large amounts of the solar electricity generated during the day in batteries, for later use to meet power demand in the morning or evening**.

In our simulation, we assumed a total installed storage capacity of 72 GW/184 GWh. This means that **much of the balancing power is provided by the storage batteries**. Currently, pumped hydro accounts for only 1% of total electricity supply, but in our simulation, pumped hydro and storage batteries (together) account for 8% of supply. Thus, in this future era when renewable energy provides 80% of total electricity, storage battery technology will play a vital role.

Fig. 15 Trends in Battery Prices

Figure 1: Volume-weighted average lithium-ion battery pack and cell price split, 2013-2023



Source: BloombergNEF. Historical prices have been updated to reflect real 2023 dollars. Weighted average survey value includes 303 data points from passenger cars, buses, commercial vehicles, and stationary storage.

Source: Bloomberg NEF, *Lithium-Ion Battery Pack Prices Hit Record Low of $139/kWh* (November, 2023)

Explanation: This chart plots the weighted average prices of lithium-ion battery packs and cells for each year from 2013 to 2023, showing a total drop of 80% over this period.

[47] At a conversion of 150 JPY to the USD
[48] Carlos Ruiz, Martina Lyons, Isaac Elizondo Garcia and Zhaoyu Wu (2023), *Sodium-ion batteries ready for commercialisation: for grids, homes, even compact EVs*

Costs Do not Increase and are Less Sensitive to Fossil Fuel Prices

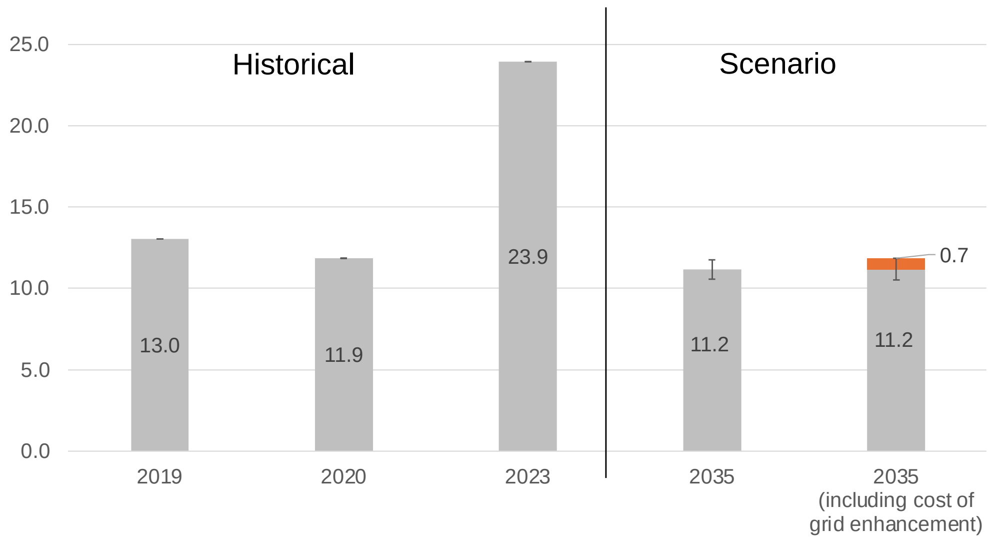
What about electricity generation costs? We calculated the average annual generation cost of electric power based on the results of this simulation (Fig. 13) and compared it to past power generation costs (Fig. 16).[49] For actual results, we used the nominal prices for each year. For our scenario, we used 2023 prices.

Our results showed that even with the substantial deployment of storage batteries, the cost of electric power generation in 2035 will be lower than the cost in 2020 (pre-invasion to Ukraine). And **even if the cost of grid enhancement from the present time is added**, **the cost will be on a par with the 2020 level**.

Since only a small quantity of fossil fuels is used in this scenario, the spike in fossil fuel prices due to events such as the invasion to Ukraine has little impact on generation costs. If we calculated power generation costs increase in 2023 using natural gas and coal prices[50] before and after the invasion to Ukraine, the cost increase would amount to ¥4.5–6.5/kWh. In contrast, the increase in power generation costs under this scenario is only ¥1.5–2.5/kWh, a much smaller amount.

Making renewables the linchpin of our energy mix means moving toward **an energy supply structure in which fluctuations in fossil fuel prices have small influences such as increase of electricity costs.**

Fig. 16 Comparison of Power Generation Costs in 2023 and 2035 (Error Bars Represent Range of Cost Settings)



Explanation: In 2035, the cost of power generation centered on renewables will be approximately the same as the recent level, even the costs for installation of a large amount of battery storage and grid interconnections enhancement from the current level (orange part of the right bar) are included.. While the fossil fuel price increase due to an event such as the invasion to Ukraine would cause a cost increase of ¥4.5－6.5/kWh in the 2023 energy mix, in the 2035 energy mix, the same event would only increase power cost by ¥1.5－2.5/kWh.

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[49] The figure for 2020 is calculated by dividing the market size of the power generation sector of ¥10.1 trillion in the Ministry of Economy, Trade and Industry data by the amount of electricity generated at the transmission end. The figure for 2023 is calculated by subtracting the estimated revenue from wheeling charges (¥4.6 trillion) from the total revenue of all companies reported in the *Electricity Market Report* (¥18.9 trillion), and dividing by the quantity of electricity generated at the transmission end, assuming that the expenses of the entire retail electricity industry amount to ¥1 trillion. Note that ¥3.1 trillion worth of subsidies for rapid change mitigation are also considered. For 2035, CAPEX and OPEX in 2035 were set and calculated for the 2035 power supply structure. Grid enhancement costs (orange) were calculated by adding the costs of the extra transmission lines that were added in this scenario (e.g. Hokkaido-Tohoku transmission lines) to the scenario of locating renewable energy systems where the demand is, as envisaged in the OCCTO Master Plan, assuming an annual expense ratio of 10%. The settings for each type of power generation are presented in the full version of this scenario.

[50] Assumed prices of $15/MMBTU and $350/ton

Balancing Power is Provided Mainly by Storage Batteries

Storage batteries and renewable energy systems also provide the balancing power[51] that is essential for stabilizing an electric power system. In our simulation, storage batteries, pumped hydro, and renewables (solar, wind, and hydro) were selected because they minimize operating costs. These energy sources do not involve fuel costs, and none of them suffer from significant efficiency losses when operational adjustments are made. In other words, even in our hourly calculations, we showed that the combination of storage batteries and renewable energy is sufficient to achieve stability of electricity system. Although inertia is not explicitly modeled in our simulation, a recent large-scale pilot experiment in Ireland that tested a combination of storage batteries and synchronous condensers, as well as storage batteries alone, serves as a useful reference.[52] It is clear from our hourly simulation results that **even without the presence of thermal power plants, the assumed balancing power can be adequately provided** by a power generation system focused on renewables.

Using 7–9% Surplus Renewable Power to Make Inexpensive Domestic Hydrogen

The amounts of surplus energy produced by renewable energy sources as a result of optimal operation under the assumptions of this simulation are 7% for solar and 9% for wind.[53] These are the quantities of electricity that cannot be used, even under optimal use.[54] This amount is equivalent in energy terms to the quantity of hydrogen needed for hydrogen power generation in this simulation. That is, if this excess power were used to produce hydrogen,[55] instead of being curtailed, it would be enough to provide all the hydrogen electricity with domestic green hydrogen.[56]

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[51] In our simulation, the Frequency Containment Reserves (upward and downward direction) and Frequency Restoration Reserves (upward and downward direction) were set with the constraint that the equivalent of 3% of demand is required. The simulation was also set to allow hourly adjustments of 5% of solar and wind power output.

[52] In Ireland, an island country with a large amount of wind power, a project is already to provide inertia by means of a mix of storage batteries and synchronous regulators, in addition to systems that use only storage batteries, are already under construction. (See Cameron Murray (2023), *Siemens Energy to deploy 'first' synchronous condenser-BESS hybrid project in Ireland*; and Everoze (2017), *Batteries: Beyond the Spin*.) In the U.S. and Australia, stabilization services available in the market are increasingly provided with storage batteries and power electronics. (See NREL (2020), *Understanding Inertia Without the Spin*; and Bruce Mountain, Steven Percy (2021), *Inertia and system strength in the national energy market: A report prepared for the Australia Institute*).

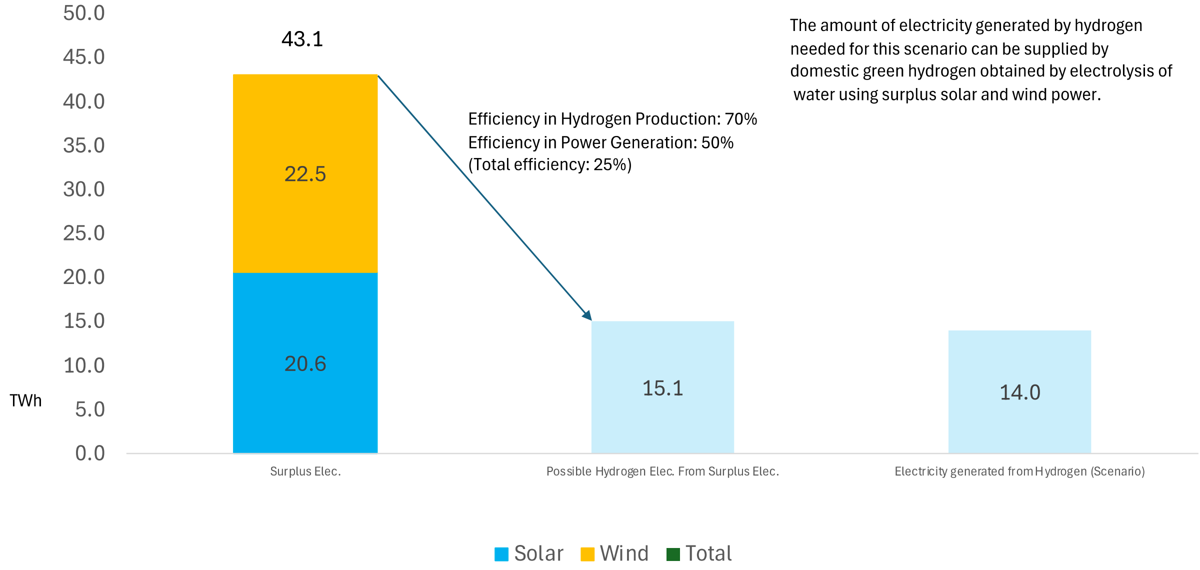
[53] Ratio of surplus electricity for each source per year

[54] Note that the deployment of demand response may reduce the surplus

[55] For the hydrogen power generation, a strategy needs to be developed considering the utilization rate of electrolysis devices and power generation facilities. It can be a case to co-fire hydrogen into natural gas-fired plants in the beginning.

[56] The amount of electricity is 43.1 TWh, so assuming electrolysis devices produce hydrogen with an efficiency of 70% and that the efficiency of hydrogen power generation is 50%, around 15.1 TWh of hydrogen power can be generated from this surplus.

Fig. 17 Quantitative Comparison of Surplus Electricity and Hydrogen That can be Generated From it, and Hydrogen-Generated Electricity Assumed in the Simulation (TWh)



Explanation: This simulation, which is closed to the electric power system, showed that if surplus electricity from solar and wind is used to generate hydrogen, the amount of resulted hydrogen was approximately equivalent to the amount of hydrogen assumed to be deployed in the simulation. This suggests that increasing the deployment of renewables will end up providing inexpensive electricity for domestic green hydrogen production. At the same time, as part of an overall national decarbonization strategy, it is important set priorities for industrial processes that can only be decarbonized using hydrogen.

Interconnections for Wind Power, Storage Batteries for Solar Power, and Solar Power should be Distributed by Peak Demand

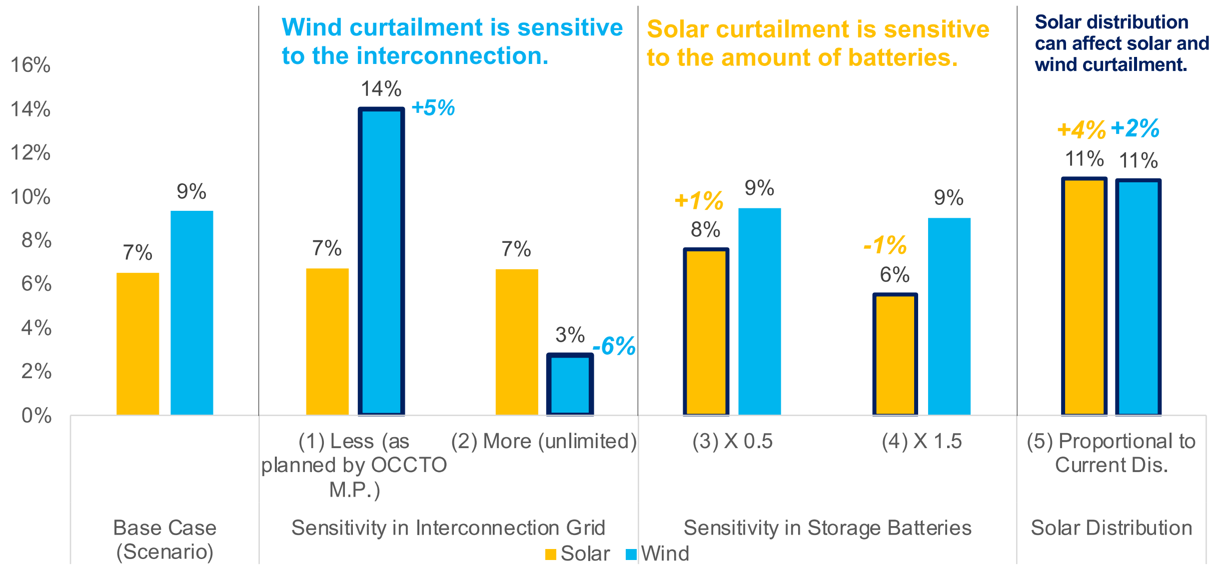
The sensitivity analysis performed for this scenario, with different level of interconnections and storage batteries, showed that interconnections impact the amount of wind power curtailment and that storage batteries impact the amount of solar power curtailment.

In particular, in Case (1), in which interconnections are enhanced less than in our scenario (base case), surplus wind power increased by 5 percentage points. Conversely, in Case (2), in which there are no interconnection constraints, surplus wind power decreased by 6 percentage points. For Case (1), we assumed the enhancement of grid interconnection by 2035 to be as projected from the OCCTO Master Plan, but we found this level of enhancement to be insufficient for the large-scale deployment of renewable energy in our scenario. We therefore believe it is necessary to **promptly update the master plan in line with the expanded scale of renewable energy deployment in the next Basic Energy Plan**.

For storage batteries, a uniform increase in non-EV storage batteries by a factor of 1.5 (50% increase) (Case (4)) reduced the surplus solar power rate by 1 percentage point, whereas a uniform increase by a factor of 0.5 (50% decrease) (Case (3)) increased the surplus power rate by 1 percentage point. Clearly, the quantity of deployed storage batteries influences the effective utilization of solar power.

We also found that it is important to decide where and how much solar power capacity to install. In Case (5), the “distribution based on current installed capacity” assumed in the OCCTO Master Plan results in a large quantity of solar capacity being installed in Kyushu. As a result of this, the surplus rate of both solar and wind power increases. Under our scenario (base case), solar capacity is installed in accordance with the peak demand in each area, suggesting that a strategy for determining where to deploy how much solar capacity is important.

Fig. 18 Sensitivity Analysis: Impact of Solar and Wind Power on Surplus Rate (Ratio of Surplus Power to Total Generated Power for Each Source)



Explanation: In Case (1), in which the enhancement of grid interconnections between Hokkaido and Tokyo by 2035 is less than projected by the OCCTO Master Plan, the wind power curtailment rate increased by 5 percentage points. In Case (2), with unlimited interconnections, the wind power curtailment rate decreased by 6 percentage points. In Case (3), in which storage capacity increases by a factor of 0.5 (50% decrease), the curtailment rate solar power rose by 1 percentage point. In Case (4), in which storage capacity increases by factor of 1.5 (50% increase), the curtailment rate for solar power dropped by 1 percentage point. In Case (5), in which solar power capacity is distributed as it currently is, as per the OCCTO Master Plan, the solar power curtailment rate increased by 4 percentage points. As a result of the large quantity of solar power capacity being installed in Kyushu, the wind curtailment rate also increased by 2 percentage points.

An "Emergency Response" for Cloudy and Windless Conditions: Let's Start a Discussion for 80% RE future

In order to move toward 80% renewables by 2035, it is important to start discussing how to address the issue of when there is no sunshine or wind in Japan for long periods of time, i.e., the "cloudy and windless" problem.[57]

The IEA defines "phases of system integration of variable renewables (VREs)" based on the characteristics of the grid and according to the ratio of VRE sources such as solar and wind (Fig. 19). In Japan, the Kyushu region appears in the analysis as Phase 3, while Denmark is classified as Phase 5 and the island countries of the U.K. and Ireland are Phase 4.

The "cloudy and windless" problem is being discussed in Germany, a country aiming at 100% renewables that is at a more advanced stage of renewables development than Japan. In Germany, discussions are underway to discuss the creation of a mechanism to address this issue. Hydrogen has been selected as key element in solving the problem.[58]

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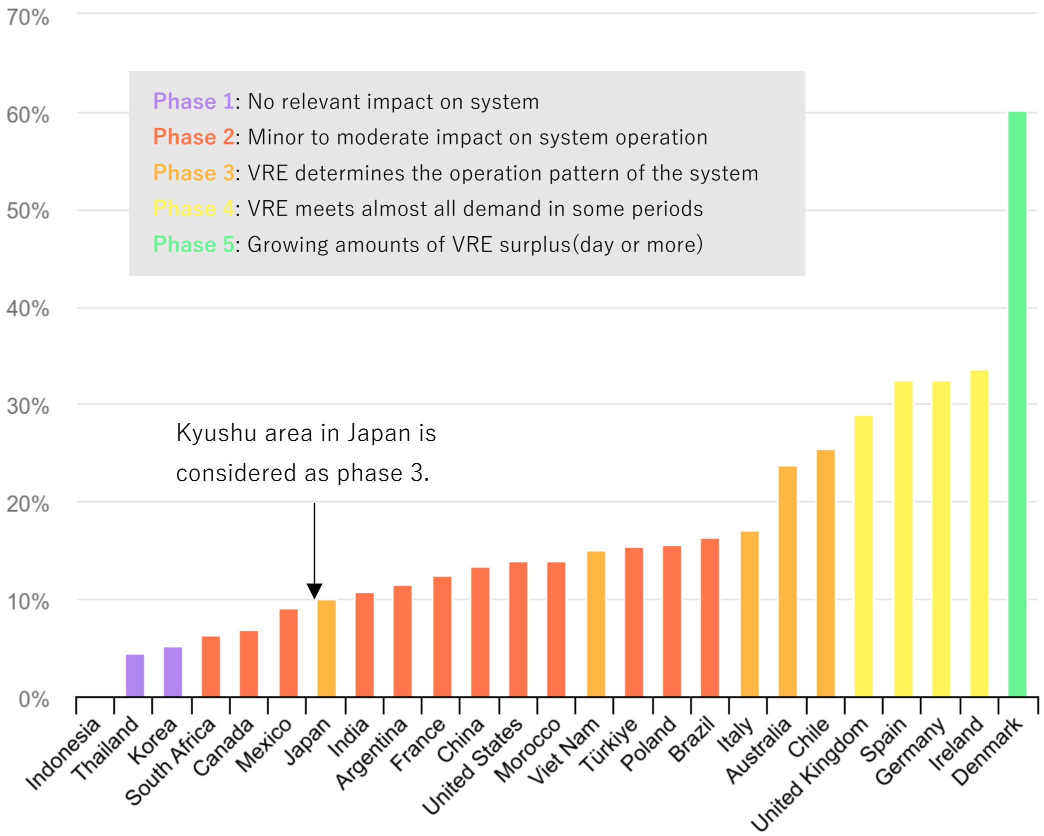
57 The analysis presented in the report ***Renewable Pathways: The Strategies to 100% RE for a Carbon-neutral Japan*** *[in Japanese]* published in 2021 by Renewable Energy Institute, which looked at solar and wind power generation across Japan in 2018 and 2019, found that combined solar and wind power output fell to 10% or less for no more than 18 hours.

58 The Power Station Strategy of the German Federal Ministry for Economic Affairs and Climate Action (BMWK) provides a framework for investment in gas-fired and other thermal power plants that can be converted to hydrogen. (See BMWK (2024), *Agreement on Power Station Strategy*.)

On the other hand, the option of letting the market sort out the problem also has some support. **Since hydrogen storage is very costly**, some analysis suggest that cost can be cut by a factor of 13 to 38 simply by **optimizing the mix of renewables and system design according to local weather and current conditions**.[59]

As climatologist Ken Caldeira says, "Controversies about how to handle the [electricity] endgame should not overly influence our opening moves."[60] At the same time, if the aim is to increase the share of renewables further, discussion needs to start now, including the question of how much risk we should prepare for.

Fig. 19 Annual Share of Variable Renewables (VRE) and Corresponding System Integration Phase (2022)



Source: IEA (2024), [Annual variable renewable energy share and corresponding system integration phase in selected countries/regions, 2022]

Explanation: The response will vary according to the degree of progress in deploying variable renewable energy (VRE) sources such as solar and wind. Japan needs to start discussions about how much risk it should prepare for and what kind of measures it needs to take in preparation for reaching more advanced phases like Denmark and Ireland

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59 Sammy Houssainy, William Livingood (2021), *"Optimal strategies for a cost-effective and reliable 100% renewable electric grid"in Journal of Renewable Sustainable Energy*, Vol. 13, 066301

60 Ken Caldeira (2018), *Geophysical Constraints on the Reliability of Solar and Wind power in the United States*.

Column: Toward Sustainable Bioenergy Use

Under this scenario, approximately 11% of bioenergy generation is expected in 2035. The details of this bioenergy scenario for FIT projects are largely in line with the forecasts of industry groups, and not significantly different to those of the Basic Energy Plan. However, our estimate includes private power generation, which is not included in the Basic Energy Plan, and the conversion of some coal-fired power plants to 100% bioenergy plants. This explains the gap between the estimates.

Sustainable use of bioenergy is a prerequisite for bioenergy power generation. For this reason, comprehensive checks of environmental, human rights, social, and other issues are vital. Although importing biofuels is not entirely out of the question, it requires an understanding of the social and environmental conditions in the countries or regions where the fuel is produced, as well as the development of a supply chain that does not undermine sustainability. Assessment of lifecycle greenhouse gas emissions, whether domestically produced or imported, must be based on appropriate LCA methods.[61] It is also important to prioritize the use of low-risk materials such as waste and residues.

Under the FIT scheme, sustainability criteria have been set for crop residues. The Forestry Agency's guidelines for certification of legality have been used for woody biomass, but they are due for review in 2024. Non-FIT projects such as decarbonization power auctions will need measures similar to FIT sustainability standards. Furthermore, private-sector initiatives such as CDP and RE100 require to use bioenergy of verified sustainability.

The use of third-party certification systems has become a common feature of this kind of sustainability certification. However, even certification systems based on annual audits are imperfect, and therefore power producers that supply renewable electricity generated from bioenergy need to deepen their understanding of the supply chain and make use of the certification systems as an integral element of their risk management.

[61] Greenhouse Gas Protocol, the global standard for corporate GHG accounting and reporting rules, is currently developing the *GHG Protocol Land Sector and Removals Guidance*, which expects companies to calculate and report bioenergy lifecycle GHG emissions as Scope 1, 2 3.

3. Recommendation: In What Ways Can Japanese Companies Compete Globally, and How Can Japan Secure Profitability by Embracing Decarbonized Technologies?

To Expedite the Implementation of Renewable Energy[62]

If Japan is to achieve early success in its decarbonization efforts, expediting the integration of renewables is essential. Formulating a national plan is key to surmounting the array of challenges attendant to this objective, which significantly amplifies renewables' penetration vis-à-vis the prevailing Basic Energy Plan. This strategic undertaking is poised to attract investments and form the cornerstone for fostering diverse environmental landscapes.

Solar PV sector necessitates enhancements in grid connection, output control, and the tendering system. Promotion measures encompass mortgage tax breaks for housing and tax credits for corporate PPAs. Moreover, regulatory reforms for agricultural land, which involve extending the permission period for conversion, are paramount. The government is urged to institute relevant laws and guidelines to promote the introduction of infrastructure facilities, such as car parks, railways, and airports, while simultaneously ensuring safety. Furthermore, initiatives to bolster community-led projects are indispensable for stimulating the local economy.

To advance the expansion of wind power, it is imperative to expedite the processes of licensing and environmental impact assessments by standardizing regulations and procedures at the international level and leveraging digitalization. Early-stage coordination at the local level, guided by both national and local governments, must be extended. The challenge concerning offshore wind pertains to the coordination of sea area usage, necessitating strong determination from the national government to accelerate the implementation of these measures. To realize the deployment of 25 GW of implantable and 20 GW of floating wind power by 2035, accounting for an approximate lead time of six years from project decision to operational commencement, it is essential to designate 40 GW of the project area by the end of the 2020s, with a corresponding decision on the operator's selection by that time.

The expansion of storage batteries and interconnection lines is paramount to achieving the targeted 80% reliance on renewables by 2035. Monetizing storage batteries' contributions to grid stability and examining policies to facilitate domestic production are also key considerations. **Local communities' opposition to solar and wind power development** needs to be addressed. It is important to expand the approach of community revitalization through renewables led by local government to include local companies. When dealing with external developers, requiring prior dialogue and a framework that stimulates the local economy may be effective. For example, local companies and financial institutions could be mandated to participate in construction and operation at a certain percentage of the order value.

[62] See the full version of this scenario for a summary of the necessary measures.

Accelerating the Enhancement of Storage and Grid Interconnection

To attain an energy composition consisting of 80% renewables by 2035, it is imperative to augment the number of storage batteries and interconnection lines. Presently, storage batteries are cost-effective, and technological advancements such as sodium-ion batteries, which exhibit less resource imbalance, are underway. It is of utmost importance to establish a market framework that appropriately monetizes the contribution of storage batteries to grid stability and the integration of renewables. Furthermore, deliberation on the potential implementation of policies to incentivize domestic production should be on the agenda.

The reinforcement of interconnection lines should surpass the originally outlined plans in the OCCTO Master Plan, which was predicated on achieving 50-60% RE by 2050. Urgent consideration for a revised plan, duly acknowledging the substantial reduction in storage battery costs, is necessitated.

For Ensuring Fairness in Grid Connection and Use

Grid-integrated renewables are used by business and other consumers looking to use renewable resources. The unauthorized access of customer information by group companies of transmission and distribution companies has raised significant concerns about the independence of transmission operators. To ensure fairness and transparency in grid connection and utilization, **stricter separation rules and more stringent monitoring** are necessary to enhance the independence of transmission and distribution companies.

Creating an Environment where Business can Decarbonize and make money

Business is not structured to “voluntarily” lose money, so the decarbonization must be a profitable endeavor for them**.**

Japanese multinational companies are facing a situation where failure to decarbonize could result in their exclusion from the supply chain or put them at a competitive disadvantage internationally due to EU’s Carbon Border Adjustment Mechanism (CBAM). The carbon pricing is a means to earn money by reducing emissions to add more economic value to the reductions. In Japan, it has been announced that certain companies will be required to participate in the GX-ETS starting from FY2026. However, what is crucial is the level of the emissions cap/upper limit. **The cap level must be set at a level that provides sufficient economic incentives**.[63]

[63] In our dialogue with companies, we hear that when developing business plans, it is difficult to build bold investment plans when the level of future carbon prices is cheap or invisible.

Leaving No One Behind: Managed Phase-Out of Coal-Fired Power

The urgent climate crisis demands swift and decisive action. Companies and industries need to transit their business practices should receive the necessary financial support from the government, such as establishing funds, providing subsidies, and offering compensation, to ensure a just transition. Prompt dialogues among all involved parties are crucial to reach a consensus and avert a severe climate crisis caused by the expected impact of phasing out coal-fired power plants by the early 2030s. Regarding financial relationships with coal-fired power producers, financial institutions are uniquely positioned to support credible coal phase-out plans. It is recommended to take actions by developing **a "managed coal-fired power phaseout" mechanism**[64] **to finance regional decarbonization projects**, including obtaining credits for CO_2 emission reductions from early plant shutdowns and generating profits from alternative strategies like offshore wind farms. The support fund for regional development provided by Germany's "compensation" to coal-producing regions for the phase-out of coal-fired power can serve as a model for cooperation with local authorities to foster new industries in line with the envisioned decarbonization era. It is crucial to collaborate with local governments and seize the **opportunity to develop industries for the new age of decarbonization, as aspired by the region**.

The Basic Energy Plan should be Decided by a National Debate on the Latest Trends

The 7th Basic Energy Plan represents the final opportunity to actively transition to a new energy system emphasizing renewables. It is essential to engage in scientific discussion that considers the most recent advancements and trends. Specifically, within the realm of renewables, there has been a notable emergence of decentralized and demand-driven power system operation technologies, accompanied by significant cost reductions in solar and wind power as well as storage batteries. **In light of these significant developments**, it is important to reflect the perspectives of various segments of Japanese society are taken into account, including demand-side companies, financial institutions, civil society organizations, and future generations, who may not have had the chance to express their views on the future of energy.

[64] GFANZ (2023), *Financing the Managed Phaseout of Coal-Fired Power Plants in Asia Pacific*; Glasgow Financial Alliance for Net Zero (GFANZ), which is aiming for a net zero transition that takes into account investment and loan choices, plans to conduct a case study of a managed coal-fired power phaseout in Japan.

4. Story: How is the Life in REI's Scenario in 2035?

In August 2035, the recorded top temperature in Kumagaya city was 44°C. Our town is also hot during the day, but thanks to the all the sunlight that generates plenty of electricity, power is cheap. So, even with the air conditioning on, our electricity bill is not high. The electric car we bought five years ago is set up so that while it is unused, it automatically stores electricity when power is cheap and sells electricity to the grid when power is expensive. This helps to cut our monthly car loan repayments considerably.

Five years ago, we moved to a town in Hokkaido. Depopulation used to be a problem, but since the offshore wind farm was located here, the town has become vibrant. Since I work online, I can work from anywhere, but my husband works near the port as a manager of an offshore wind power construction project. A data center was attracted to the port district because of the offshore wind project, and a new steel mill has been built, so the town is lively and prosperous. There is also a very good childcare center within walking distance that our eldest daughter (aged 2) attends.

One of my fellow-mum friends works at a steel mill that was built eight years ago. The mill decides its operating schedule by predicting when electricity will be cheap, based on how the wind will blow and how the sun will shine in the week ahead. Since electricity is usually cheaper during the daytime, the schedule is healthy for workers. On the other hand, when electricity prices are very high, my friend gets a day off from work. Similarly, in my data analysis work, computation is concentrated at times when electricity is cheap, so I also get days off unexpectedly. When my weekly schedule is released and I suddenly find that I have a day off, my friend often has the same day off. On these occasions, we go out for lunch together. These are what we call "cloudy and windless" days.

I have heard that the average global temperature is expected to begin dropping around the time our children reach adulthood. Our time may go down in history books as the hottest era ever. It was a difficult time, but thanks to policies aimed at increasing the use of renewable energy, the materials industry has prospered, and the Japanese economy has recovered its vitality. Japan's trade deficit has fallen because energy imports have declined, and the cost of electricity has finally stabilized, thankfully. The cost of living is relatively low in wind-powered towns like ours, probably due to the low cost of electricity and hydrogen here. I've heard that hydrogen costs twice as much in Tokyo.

We are expecting our second child early next year. Our family is happy to keep living in this easygoing town that is thriving due to the local offshore wind power farm.

Energy Transition Scenarios for Decarbonization
Based on 80% Renewables Electricity by 2035

August 2024

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