The Energy Transition toward Carbon Neutrality

Perspectives on Energy Systems in Light of the Recent Rise in Energy Prices

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October 01, 2022

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0. Introduction
- Purpose and Outline of this Paper -

In recent years, rising fossil fuel prices and carbon neutrality efforts in many countries around the world have led to changes in the future form of energy systems and their transition into that future. Therefore, this paper describes perspectives for considering the shape of energy systems in the future as well as activities that are given high priority in the transition period. Recent trends and issues assumed to arise in the future are also presented.

Please note that, while the case studies in this paper discuss trends of and analyze the energy system of Japan, the paper was compiled under the assumption that this can be applied also in other regions that are on their way to carbon neutrality. This paper was prepared with the intention to provide an idea for concepts of and approaches to future energy systems or additional measures.

We expect that the energy systems of the future will be more complex than now, since they must take into account various evaluation indicators such as carbon neutrality, energy security, safety, and further economic growth through large-scale investment and technology development. When considering their ideal form, it will be necessary to consider factors such as technology innovation, energy decentralization, digitalization, and sector coupling. Therefore, we believe that we need to aim for overall optimization from a *systemic perspective*, that is, we need to consider, for example, how individual initiatives affect other initiatives or the overall optimization.

For example, an increase of renewable energy generation could promote carbon-free power supply and also contribute to a reduction of power generation costs in regions with good locational conditions. On the other hand, since power sources such as sunlight, wind and the like are subject to natural fluctuation, additional costs are incurred to make sure that the supply of electric power matches the demand (grid stabilization). Measures to deal with the disposal of solar panels will also be required. The result may be that, while CO_2 emissions are further reduced and energy self-sufficiency is enhanced, electric power costs will rise. It should be noted that without a systemic perspective, the optimization may become too specific, without considering trade-offs among evaluation indicators and technologies. An effective means for realizing a systemic perspective is a simulation of the entire energy infrastructure, as it can support decision-making by quantitative assessments of evaluation indicators and causes for trade-offs. As an example, this paper presents a case study of a simulation of the entire supply and demand structure of energy in Japan.

Further, to deal with the rising fossil fuel prices and accelerate the process toward resource and energy security in the short term while realizing carbon neutrality in the future, we believe that it will be necessary more than ever before to: (1) transform the energy system (decentralization, digitalization, sector coupling), (2) maximize energy savings, (3) achieve a circular economy (recycling of resources and energy), and (4) promote Negative Emissions Technologies (NETs) (build a framework for international collaboration). This paper also provides an overview of these four activities.

1. What are the Current Issues in Energy?
- What is Happening Now? -

In various countries, the transition to carbon neutrality is making progress, and there are proactive initiatives for the social implementation of renewable energies, clean hydrogen, and other decarbonization technologies. Meanwhile, the reliance on specific countries for a fuel shift to natural gas has been recognized once again as an energy security issue, especially in Europe.

Since the adoption of the Paris Agreement in 2015, the number of countries aiming to achieve carbon neutrality (also called net-zero CO2 emissions or decarbonized society) has been increasing, and with the announcement of the special report "Global Warming of 1.5˚C" by the Intergovernmental Panel on Climate Change (IPCC) in 2018, even more countries joined. In 2021, the countries striving to become carbon neutral accounted for more than 70% of the global emissions (fig. 1).

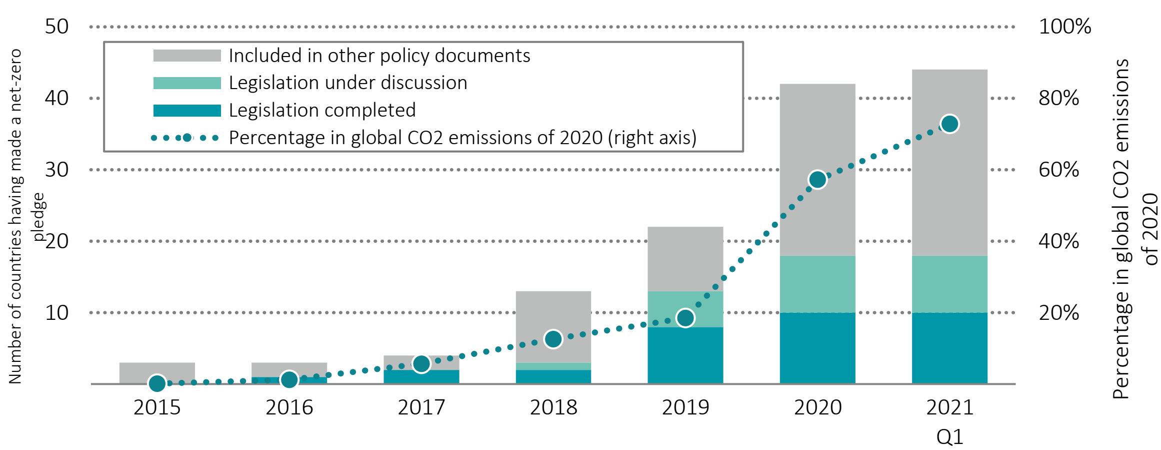
As a result, each country has launched new measures (legal systems, technology development, market design, etc.) to realize carbon neutrality.

The amount of global investments related to the energy transition has been on the rise since the 2000s. Investments by the private sector in 2004 amounted to 32 billion US dollars, and increased to 210 billion in 2010 and even to 595 billion in 2020. Additional investments for a post-COVID-19 green recovery were made in 2021, resulting in a total global investment of 755 billion US dollars (approximately 98 trillion Japanese yen). More than half of the global investment amount related to the energy transition is for renewable energies and the electrification of transportation, followed by the electrification of heat, nuclear power, and sustainable materials.

When looking at the budgets of public institutions for environmental technology as another indicator, we can see that they have been on the rise since the 2000s. While the total budget of the European Commission and 32 other countries of the world was 10 billion US dollars in 2000, it grew to 16 billion in 2010 and 22 billion (equivalent to approximately 2.9 trillion Japanese yen) in 2020. The breakdown is, in descending order of size, energy conservation, renewable energy, nuclear power, power- and energy storage, hydrogen and fuel cells, and others.

Various countries are aiming for carbon neutrality and are making proactive efforts for the social implementation of renewable energies, clean hydrogen, and other decarbonization technologies.

Figure 1: Spread of net-zero pledges



Sources: International Energy Agency, "Net Zero by 2050" (2021), BloombergNEF (January 2022), "Energy Transition Investment Trends 2022," IEA (updated on May 3, 2022), "Energy Technology RD&D Budgets"

In addition to environmental protection, the reasons why countries are aiming for carbon neutrality include the purpose of moving away from fossil fuel, as reserves are unevenly distributed and energy security is an issue.

Europe, the US, and Japan experienced an oil shock twice in the past and see an urgent need to move away from crude oil in particular. In recent years, there has been a fuel shift to natural gas. Natural gas has a low emission factor and global warming potential and is the fuel of choice also in a fuel shift from coal.

Europe and Japan had increased their imports of natural gas from Russia, which is one of the countries with the largest resources of oil, gas, and coal in the world. Europe heavily depends on energy imports especially from Russia. 23% of the oil, 34% of the natural gas, and 42% of the coal in Europe are imported from Russia. In Japan, 4% of the oil, 9% of the natural gas, and 11% of the coal are imported from Russia. While Japan does not depend on fossil fuels from Russia that much, an energy procurement strategy is extremely important because its energy self-sufficiency is low (11%).

For this reason, a disruption in the supply of fuel from Russia would greatly affect economic activities and people's lives. On a side note, the fossil fuel exports account for approximately 40% of Russia's revenue.

Russia is one of the countries with the largest resources of oil, gas, and coal in the world, and its military operations have caused many nations to reevaluate the importance of energy security.

To strengthen economic sanctions against Russia and to escape from Russia's economic sphere of influence, many countries are aiming to stop imports of Russian coal in the short term and to stop imports of natural gas and oil in the medium to long term.

On April 7, 2022, Japan and the other G7 nations announced a ban and gradual reductions on coal imports from Russia, stronger efforts to reduce reliance on Russia in energy, a ban on new investments in Russia, and more. On May 8, they further announced that they would make efforts to ban imports of oil from Russia.

In Europe, which heavily relies on Russian energy, the "REPowerEU" plan to end this reliance on natural gas and other fossil fuels from Russia by 2030 was announced (March 9). In addition, investments in Russia's energy industry and exports of goods and technologies necessary for the energy industry were basically banned (March 15).

The US government prohibited the import of crude oil, petroleum products, LNG, and coal from Russia and investments into the Russian energy industry (March 8). It further announced intentions to increase the supply of LNG to Europe (March 25).

In the European Union (EU) and other countries, there is also a gradual shift from Russian natural gas toward LNG imports from other countries. For example, there were media reports indicating that Germany would conclude an LNG supply contract with Qatar. On the other hand, there is no room for a significant expansion of global supply capacities of fossil fuel, and it is expected that there will be fierce competition among importing countries. Japan strongly depends on imported fossil fuel, and fluctuations (increases) in fuel prices caused by such changes in supply and demand are very likely to affect Japan (increase the burden on consumers).

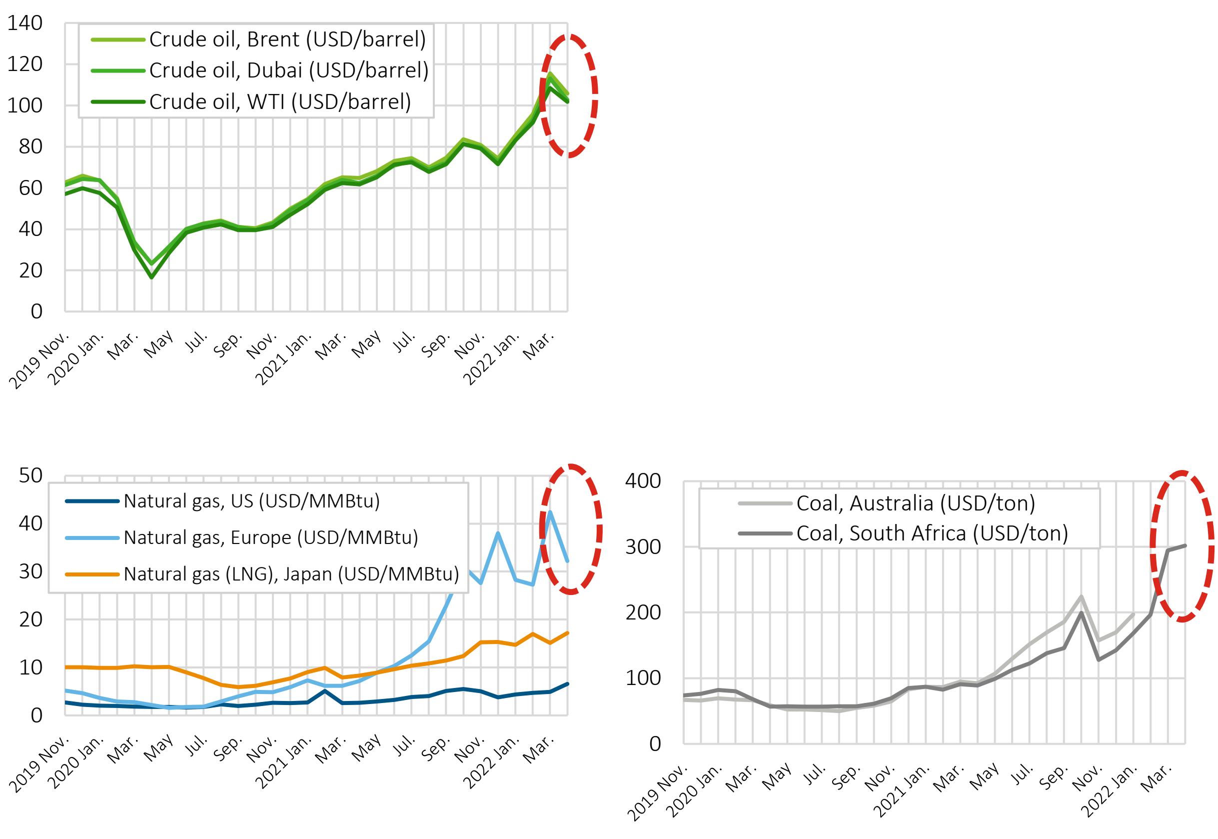
It is expected that, to break away from their excessive dependence on specific countries and to achieve carbon neutrality, many countries will move away from coal in the short term and from natural gas and oil in the medium to long term.

The post-COVID-19 economic recovery and the tight supply have kept fuel prices rising since 2021.

Russia is one of the countries with the largest resources of oil, gas, and coal in the world, and some nations strongly rely on fuel from Russia. For this reason, the import prices of fuels soared even higher after the military invasion of Ukraine by Russia in February 2022 (fig. 2). LNG spot prices reached record highs, and this price increase triggered fears that supplies may be disrupted, causing moves to switch over to fuel suppliers other than Russia.

Energy security concerns are growing, and fuel prices are rising all over the world.

Figure 2: The Ukraine crisis and its influence on fuel prices (unit: USD, nominal values)



Source: World Bank (May 3, 2022), “Commodity Prices”

2. What Transformation is Expected in Energy?
- What will Happen in the Future? -

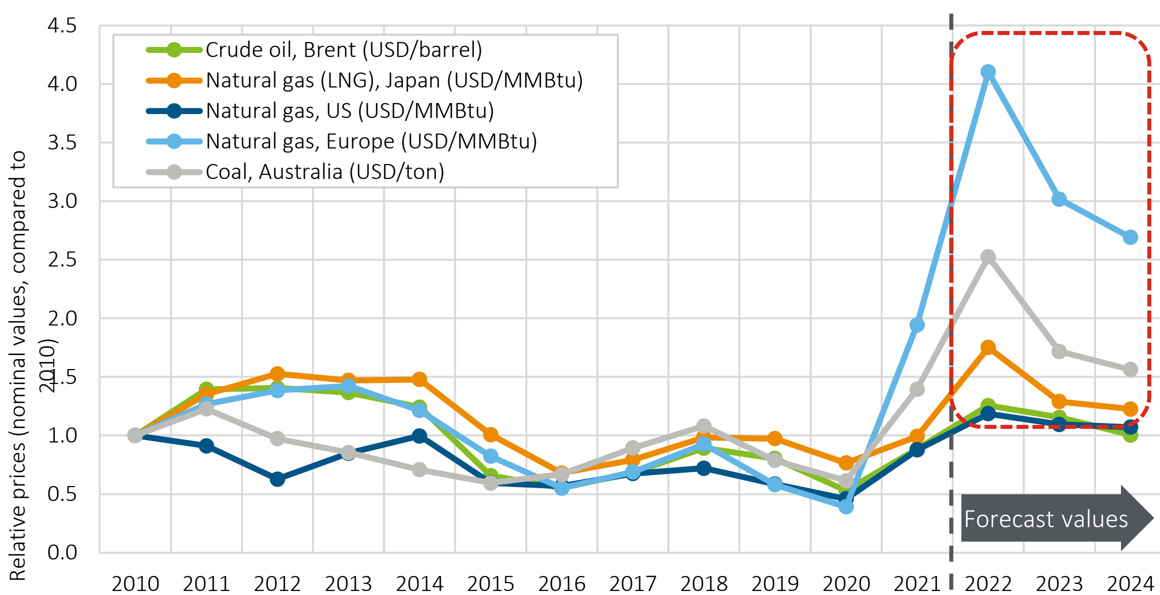
As countries seek to break away from their reliance on regions with geopolitical risks for energy, fossil fuel prices are expected to stay at a high level for several years into the future. This may accelerate the development of renewable energy and other elements that could help countries improve their energy self-sufficiency. However, some supply chains of production materials for low-carbon technologies are concentrated on some specific countries, and it will be necessary to assure energy security in the same way as for fossil fuels.

As has been discussed above, there are fears that supplies may be disrupted, and countries move to switch over to fuel suppliers other than Russia. This is expected to continue for a while, and the World Bank forecasts that, after soaring in 2022, fossil fuel prices will decrease over a span of several years. However, the forecast indicates that prices will stay high without returning to the levels of 2021 at least until 2024 (fig. 3).

Fuel prices are expected to remain high for some time.

After the military invasion by Russia, a long-term outlook for fuel prices has not yet been published, but the "World Energy Outlook 2021" of the International Energy Agency (IEA) indicates that the fossil fuel prices will vary depending on the progress of decarbonization. In the "Stated Policies Scenario," which assumes that decarbonization efforts do not make significant progress, the import prices of fossil fuels are expected rise or stay unchanged, whereas, in the "Net Zero Emissions by 2050 Scenario," which assumes that a decarbonized society will be realized by 2050, the import prices of fossil fuels are expected to decrease. The forecasted prices for crude oil and natural gas in the future strongly vary depending on the scenario.

Figure 3: Short-term forecast for fuel prices



Source: World Bank, "Commodity Markets Outlook - April 2022"

To respond to the rising import prices of fossil fuels, assure energy security even better, and fulfill the economic sanctions against Russia, various efforts have to be made.

In the EU, the REPowerEU plan is a compilation of actions to break away from the reliance on Russian fossil fuel by 2030. If this plan is realized, the Ukraine crisis may leave a medium- to long-term impact on the energy mix of Europe.

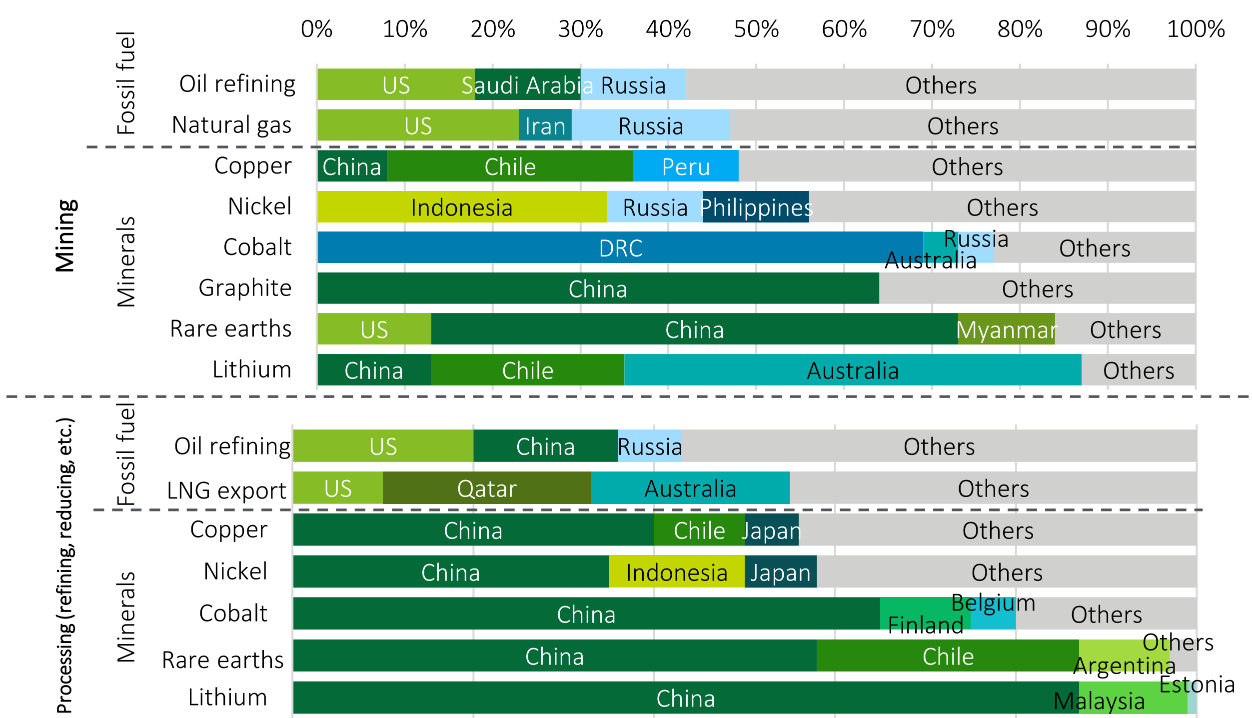
Aside from a diversification of fuel suppliers, REPowerEU lists actions for energy savings and an accelerated introduction of renewable energies. Specifically, the plan includes: a higher energy-saving target (from 9% to 13% in 2030), a higher target for the introduction of renewable energies (from 40% to 45% in 2030), decarbonization of the industrial sector by means of electrification and a shift to hydrogen, an increased production of biogas, the launch of new hydrogen-related projects, an acceleration of permission procedures for renewable energy, and a higher procurement target (to 20 million tons/year) of renewable hydrogen. Another action is to *assure access to important minerals and production capacity required for renewable energy*.

Electric vehicles, wind power, solar power, and hydrogen-related technologies use more minerals than conventional technologies. Under the Sustainable Development Scenario (SDS) of the IEA, which assumes that the targets of the Paris Agreement will be achieved, it is therefore expected that, in 2040, the mineral demand originating from clean energy technologies will have increased sevenfold for rare earths and manganese, 20-fold for nickel, cobalt, and graphite, and 42-fold for lithium as compared to the present.

While it is necessary to dramatically expand supply capacities, the supply chain is currently concentrated on a small number of countries, and there are security concerns also in terms of mineral resources (fig. 4).

Energy security in the future should not only include fuel procurement but also pay sufficient attention to precious metals and rare earths required for clean energy technologies.

Figure 4: Shares of fossil fuel and mineral production (2019)



Sources: IEA (May 2021), "The Role of Critical Minerals in Clean Energy Transitions," European Commission (May 18, 2022), "REPowerEU"

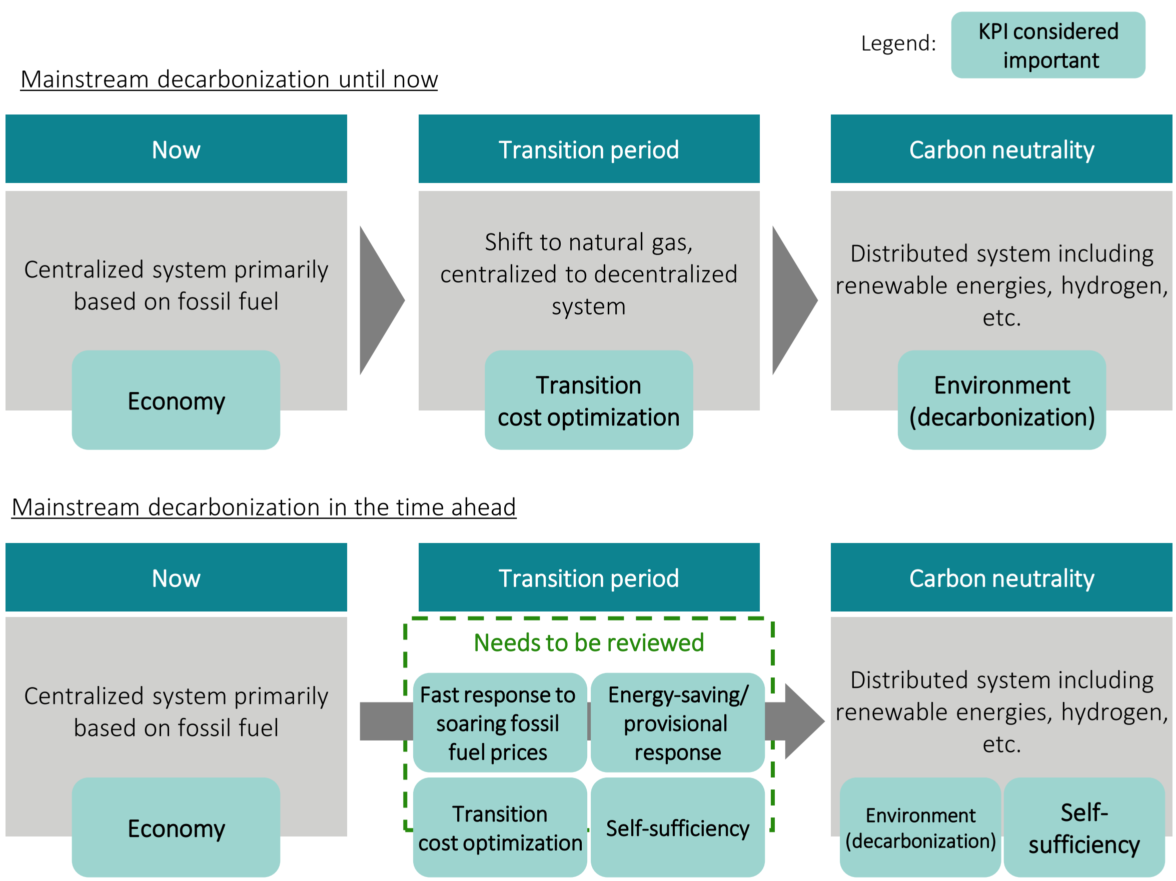
Until now, the flow for a smooth transition from the current state to carbon neutrality was probably “fossil fuel → shift to low carbon (shift to natural gas, etc.) → decarbonization.”

However, given the recent situation, the movement from low carbon to carbon neutrality could be made in a single step. The importance of self-sufficiency as a KPI will also probably grow.

For this reason, we believe that a reexamination is necessary especially for the short- to medium-term transition period (fig. 5). Measures to save electric power and energy, an acceleration of the shift to renewable energy, energy resource diplomacy, and the securement of mineral resources need careful consideration.

To realize carbon neutrality by 2050, respond to soaring prices for fossil fuel, and enhance self-sufficiency, it is necessary to review particularly the energy transition in the short and medium term.

Figure 5: Expected impacts on the energy transition



3.1. What are the Approaches to the Energy Transition?

- Perspectives of the Energy transition: Basic Policy -

More and more countries are expected to review their energy transition at a faster pace worldwide. When doing so, it is important to strive for an overall optimization using a systemic perspective while setting multiple evaluation indicators. An effective way for this is an overall analysis by means of a simulation.

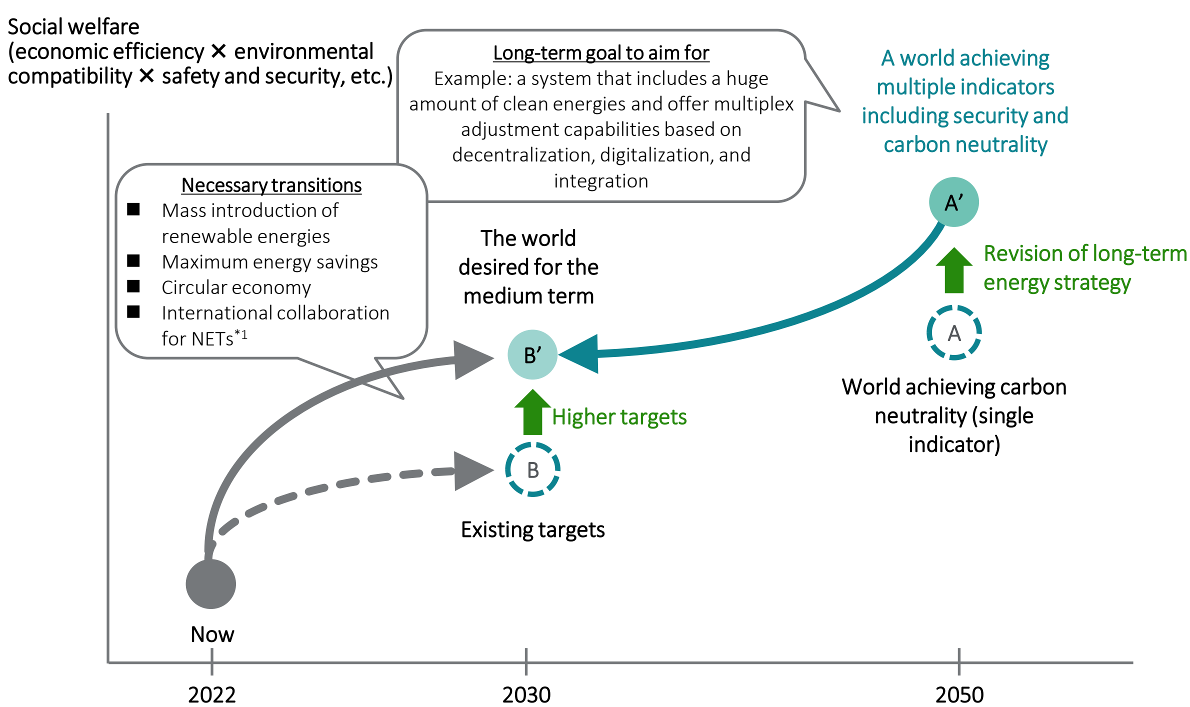
As regards the ideal form of energy, trends of recent years are showing a shift from the traditional approach of optimizing the costs of carbon neutrality toward an approach that places importance also on energy and resource security. Further, large-scale natural disasters in various regions have shown that we need a robust infrastructure that is able to withstand them. In addition, various innovative technologies contributing to carbon neutrality and the like have been researched and developed in recent years. Therefore, an overall optimization requires that social implementation is promoted with consideration for trade-offs and interaction among those innovative technologies.

It will be difficult to achieve perfect scores for all evaluation indicators as the ideal for the future. For example, if we aim for a self-sufficiency of 100% and only rely on domestic renewable energies (solar power, wind power), sacrifices will have to be made with respect to disaster resilience and energy costs. On the other hand, if we depend on inexpensive, clean energy (clean hydrogen or fossil fuels + CCS, etc.) from overseas, energy costs are likely to rise only slightly, but concerns remain in terms of energy security and a high energy price volatility.

Therefore, we need to search for an optimal energy solution based on a combination of different technologies while setting multiple evaluation indicators. The medium-term transition period also needs to be reexamined at the same time. For example, Japan's energy policy places importance on an S+3E perspective, namely to supply, based on the premise of safety, energy at low cost through improved economic efficiency while giving the highest priority to a stable supply and aiming for environmental compatibility. The future shape and the energy transition strategy need to be concretized on the basis of this approach.

It is necessary to revise the transition strategy considering factors such as environmental compatibility, cost, and security.

Figure 6: Perspectives on the form that energy should take in the future



*1: Negative Emissions Technologies: Carbon Dioxide Removal (CDR) technologies

To search for an optimal solution based on a combination of different technologies while setting multiple evaluation indicators, we need to aim for an overall optimization from a *systemic perspective*, that is, we need to consider, for example, how individual initiatives affect other initiatives or the overall optimization. For example, an increased introduction of renewable energy generation could promote carbon-free power supply and also contribute to a reduction of power generation costs in regions with good locational conditions. On the other hand, since power sources such as sunlight, wind and the like are subject to natural fluctuation, additional costs are incurred to make sure that the supply of electric power matches the demand (grid stabilization). Measures to deal with the disposal of solar panels will also be required. The result may be that, while CO2 emissions are further reduced and energy self-sufficiency is enhanced, electric power costs will rise. It should be noted that without a systemic perspective, the optimization may become too specific without considering trade-offs among evaluation indicators and technologies.

An effective means for realizing a systemic perspective is a simulation of the entire energy infrastructure, as it can support decision-making by quantitative assessments of evaluation indicators and causes for trade-offs (fig. 7).

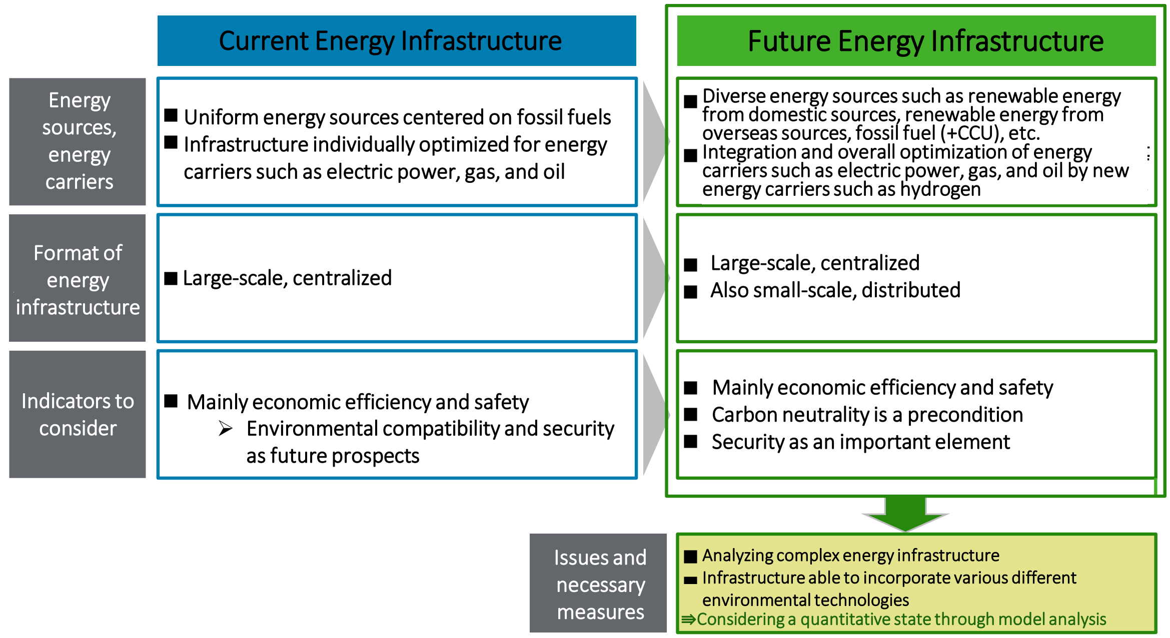
An effective way to study into the complex shape of energy is an energy system simulation.

Effective common measures for the future are: (1) a transformation of the energy infrastructure, (2) maximum energy savings, (3) a circular economy, and (4) the promotion of international NETs projects.

There are common measures which are necessary even if multiple different evaluation indicators have been set. For example, the introduction of renewable energies will steadily increase and become more decentralized than in the past, while management will become more sophisticated due to the introduction of digital technologies. For this reason, we will need an efficient decentralization and digital infrastructure ((1)). Further, to reduce future energy costs while avoiding soaring fossil fuel prices, it is important to have energy-saving measures based on the premise of constantly high fossil fuel prices and the costs of actions to reduce CO2 emissions (carbon pricing) ((2)). Moreover, a circular economy is also important to achieve more self-sufficiency and an effective use of resources and energy ((3)).

Another effective way to achieve carbon neutrality in the future are Negative Emissions Technologies (NETs). Since the locations that are suitable for NETs are unevenly distributed in the world, we believe that international collaboration is essential to use them as global resources.

Figure 7: Necessary measures and assumptions for the present and future energy infrastructure transformation



3.2. What are the Approaches to the Energy Transition?
- Considering the Shape of Energy from a Systemic Perspective: the Long-term Perspective -

As an example case of aiming for an overall optimization through a systemic perspective, the following presents a simulation of the overall supply and demand structure of energy in Japan.
For example, it is expected that renewable energies will contribute to both carbon neutrality and a higher self-sufficiency, but measures to match power demand and supply (grid stabilization) will be cost intensive. Further, the overall system will become complex.

To analyze the form that energy should take in the long term on the basis of the general situation presented above, we simulated the energy infrastructure in the years 2030 and 2050 using Japan as a model.

The evaluations in the simulation were conducted with respect to both the realization of a decarbonized society and the energy self-sufficiency of Japan. We assumed that the target for CO2 emissions reduction is a 46% reduction by 2030 (compared to 2013) and the achievement of carbon neutrality by 2050. Further, we assumed a forest sequestration of 47 million tons-CO2 and three cases of different energy self-sufficiencies (50%, 75%, 90%) (fig. 8).

Using an advanced simulation tool for energy systems, we drafted an image of the future carbon-neutral society.

The major simulation results are as follows.

- The picture of the world greatly changes depending on the energy self-sufficiency, even under the same assumption that carbon neutrality is realized
- A high energy self-sufficiency of 90% is physically feasible (requires mass deployment of offshore wind power generation)
  - The higher the self-sufficiency, the greater is the need for a grid expansion, a mass introduction of storage batteries and other adjustment capacity, and a shift to hydrogen for electric power
  - Further, since the energy system will be more complex, the utilization rates of individual facilities will decrease, resulting in increased cost
- Therefore, to achieve both carbon neutrality and energy self-sufficiency, it will be important to effectively utilize (system reform, digitalization) distributed resources (EVs, home storage batteries, demand response) and reduce costs and improve the performance of adjustment technologies through technology development while encouraging energy savings to keep the energy demand low.

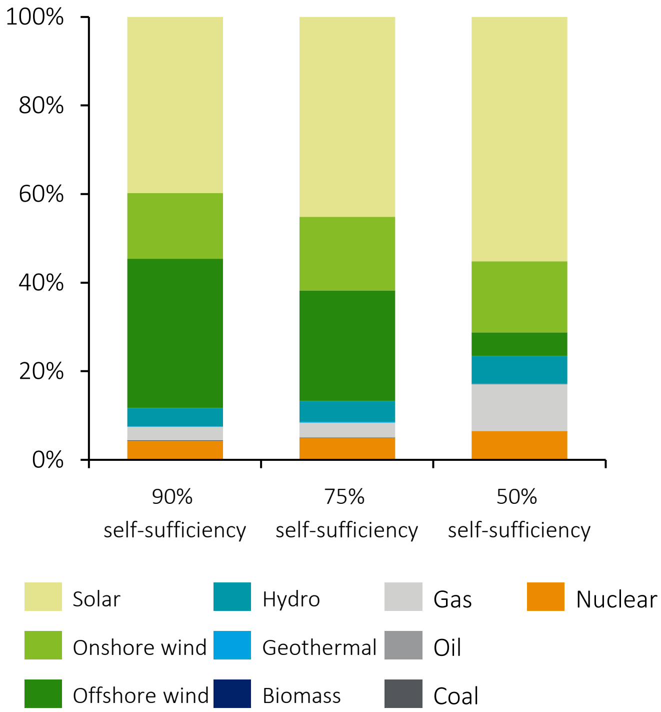
Figure 8: Main presumptions of the simulation

Target for CO2 emissions reduction	46% reduction in 2030 (compared to 2013) Carbon neutrality in 2050 (considering a forest sequestration of approx. 47 million t-CO2)
Energy self-sufficiency	50%, 75%, 90%
Nuclear power	Re-operation: yes, rebuilding: no. Plant service life: 60 years
Renewable energy	Introduction volume: cost minimization calculation in line with CO2 emission reduction targets Introduction potential: prepared on the basis of wind condition maps and information on solar radiation amounts published in Japan
Hydrogen	Hydrogen from domestic water electrolysis: energy consumption 4.3 kWh/Nm3 (alkali, 2030), costs 223,000 yen/Nm3/h (alkali, 2030), electric power procurement price was calculated endogenously Price of imported hydrogen: CIF price 15 yen/Nm3 in 2050
Grid expansion	Yes

Figure 9 compares the simulation results for the power supply mix of the different self-sufficiency targets. The first thing to note is that the share of renewable energies significantly varies depending on the self-sufficiency. The differences originate from the introduction rate of gas-fired power (clean hydrogen or natural gas + CCS) using imported gas. Note, however, that some gas-fired power remains even with a self-sufficiency of 90%. This is probably because it is economically reasonable to have a grid stabilization function based on gas-fired power.

Further, when comparing the 90% self-sufficiency with the 50% self-sufficiency, one can see that the share of offshore wind power is relatively large when the self-sufficiency is 90%. This is probably because the potential of solar panels, which are superior in terms of power generation costs, has been fully exploited and the introduction of offshore wind power plants, which are slightly more expensive but have a great potential, has made progress.

Figure 9:
Assumptions of the power supply mix (2050)



Figures 10 and 11 are Sankey diagrams, with the left side showing the energy supply and the right side the final energy consumption. The middle portion illustrates the process of the energy conversion, including the power generation sector, hydrogen production by water electrolysis, the combined use with thermal power through cogeneration, and the like. The imported energy in the upper part of the figures is supplied through a conventional supply chain, while the domestically produced energy in the lower part involves numerous intermediate processes such as energy conversion and storage or cogeneration.

The simulation result for an energy self-sufficiency of 50% shows that it is possible to achieve this level of self-sufficiency through a decarbonization of power systems mainly by means of renewable energies (fig. 10).

On the other hand, one can see that, when the energy self-sufficiency is 90%, the role of hydrogen production by water electrolysis gains significant weight. The iron and steel sector produces reduced iron in blast furnaces by use of coke, but could, to realize a carbon-neutral society, reduce CO2 emissions to zero by using hydrogen for the reduction reaction. Water electrolysis is believed to be effective also in the sense of storing surplus electric power from the higher share of renewable energy (fig. 11).

If an energy self-sufficiency of 90% is to be realized, it will be necessary that the industry sector shifts to fuel from domestic production, and this will require a mass production of hydrogen from domestic renewable energies.

Figure 10: Sankey diagram of the 50% energy self-sufficiency scenario, 2050

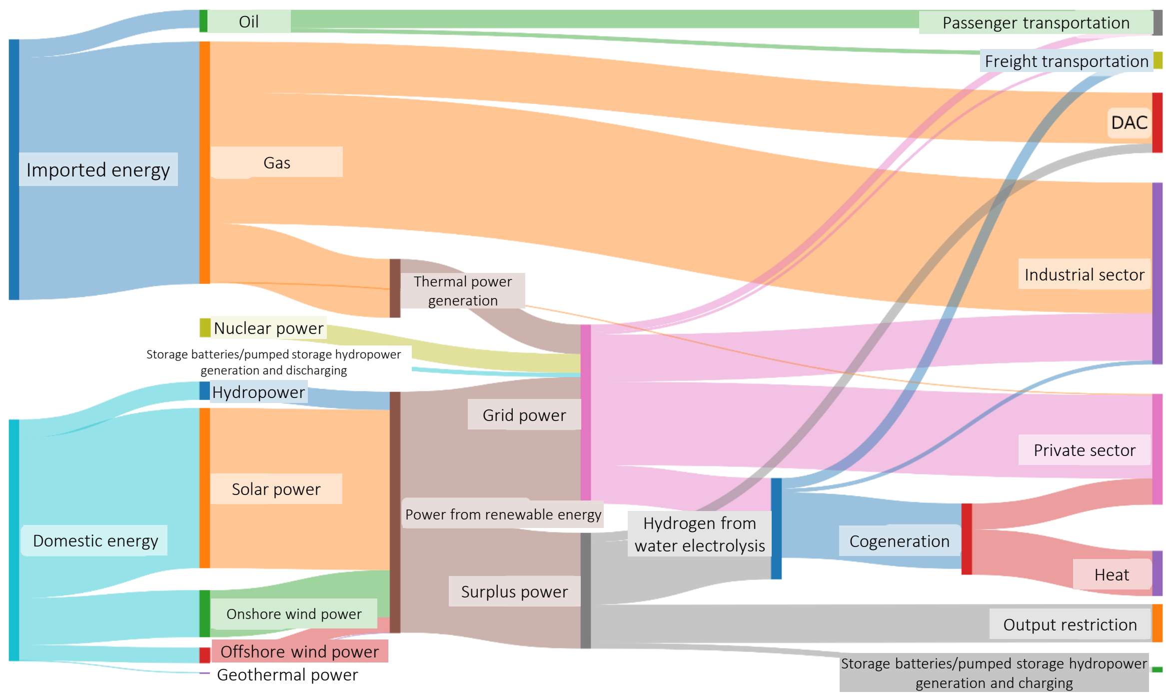
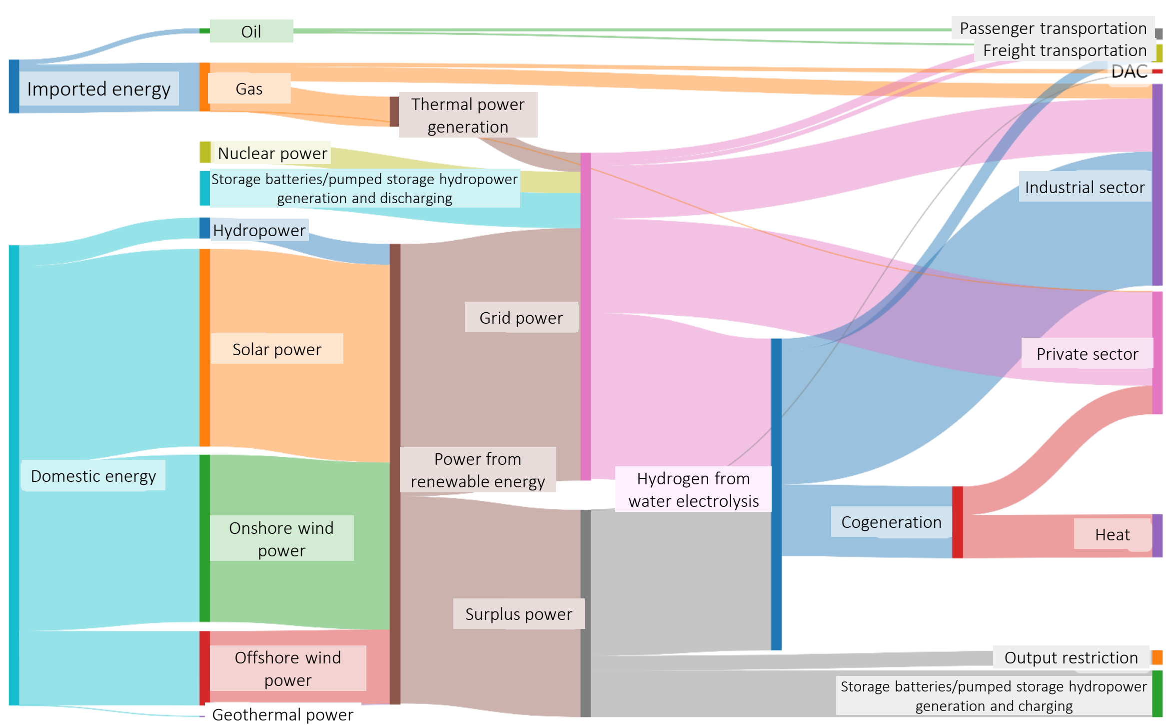


Figure 11: Sankey diagram of the 90% energy self-sufficiency scenario, 2050



* This simulation was carried out while excluding rail, ship, and air transportation from the transportation sector (both fig. 10 and 11). Further, it should be noted that imported gas may be replaced by hydrogen depending on conditions such as costs.

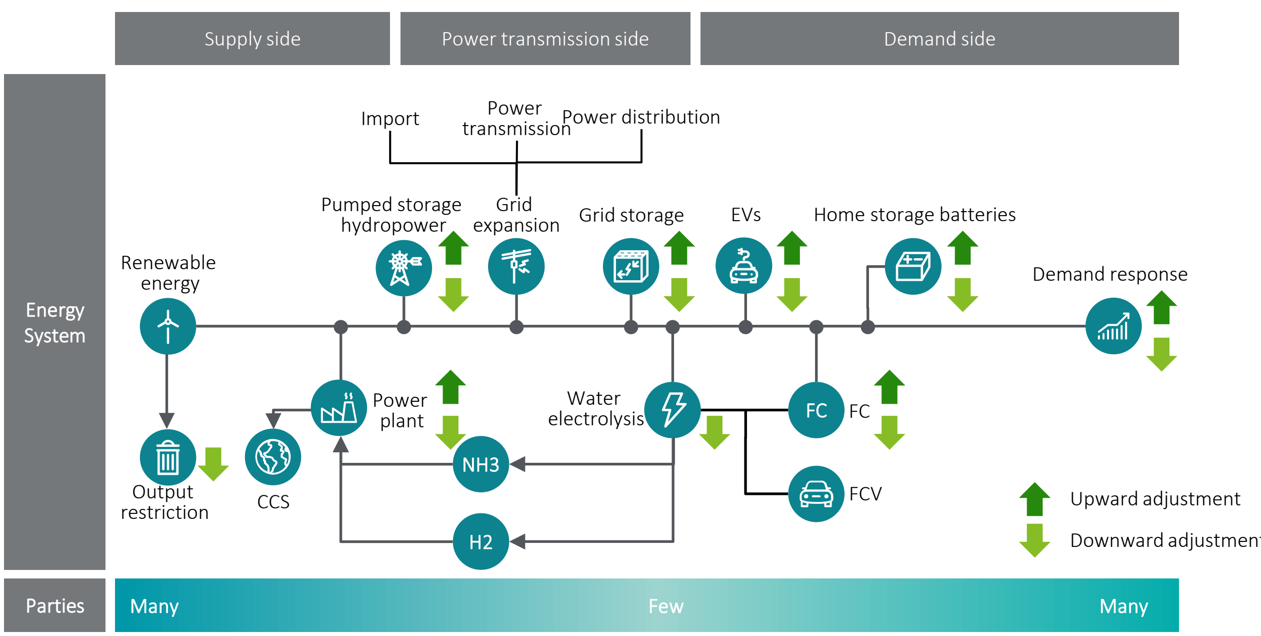
The energy systems of the carbon-neutral age are expected to include a large share of renewable energies, and to respond to the resulting fluctuations in the amount of power generation, it is important to introduce mechanisms providing the power supply side, the transmission side, and the demand side with adjustment capacities. For example, on the supply side, pumped storage hydropower could be revised, or water/ammonia power generation could be introduced. On the power transmission side, grid storage or water electrolyzers could help. Moreover, the consumer side could be provided with adjustment capacities based on home storage batteries and energy management (fig. 12).

Energy systems including large shares of these elements are expected to be complicated overall, since there will be more business forms and operators than in existing centralized energy systems including vertically integrated companies.

Sector coupling and decentralization in the energy systems of the decarbonized age will lead to significantly more complexity requiring control and collaboration among systems by way of digitalization. It is further expected that the decentralization of energy will make progress and small energy networks that supply, transmit, and consume energy on a regional basis without relying on large-scale power plants will attract attention.

The significantly higher complexity of energy systems requires control and collaboration among various types of systems through digitalization.

Figure 12: Image of the future energy system (supply of multiplex adjustment capabilities)



To enhance self-sufficiency by means of renewable energy, it is necessary to introduce equipment that contributes to the flexibility of the power grid, such as storage batteries or fuel cells. For example, in a world of 90% self-sufficiency, 215 GW in storage batteries will be needed. This is one cause for the cost increase of the power system and also a cause behind the requirement of a stable supply of rare earths and the like (fig. 13).

To achieve a high self-sufficiency, it is necessary to promote flexibility measures such as enhancements of power grids, storage batteries, and the like.

Compared to a self-sufficiency of 25%, a self-sufficiency of 90% requires at least three times more power transmission capacity in regional grids and approximately seven times more power transmission capacities for interregional transmission lines.

Already, a large number of wind farms are expected to be constructed in Hokkaido, the Tohoku region, and the Kyushu region, but it is clear that it will be necessary to perform large-scale power interchange from Hokkaido and the Tohoku region to the Tokyo area, and this requires the development of interregional transmission lines in addition to local grids. Since power grids cannot be developed overnight, it is necessary to define adjustment plans as suitable for the envisioned energy of the future not only in view of decarbonization but also from the aspect of energy security, and to coordinate between stakeholders (fig. 14).

Figure 13: Utilization rates and capacity of facilities for flexibility (2050, units: GW, %)

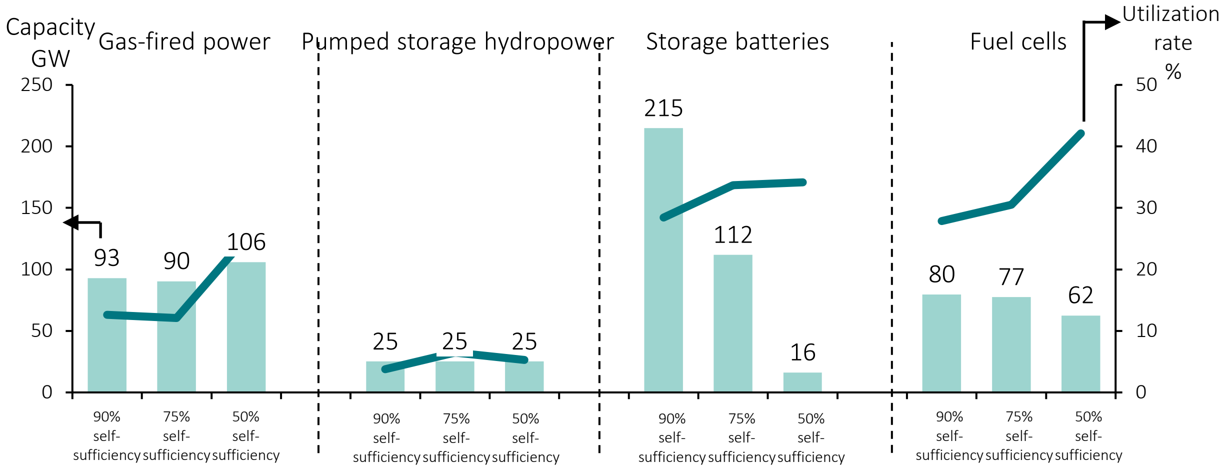
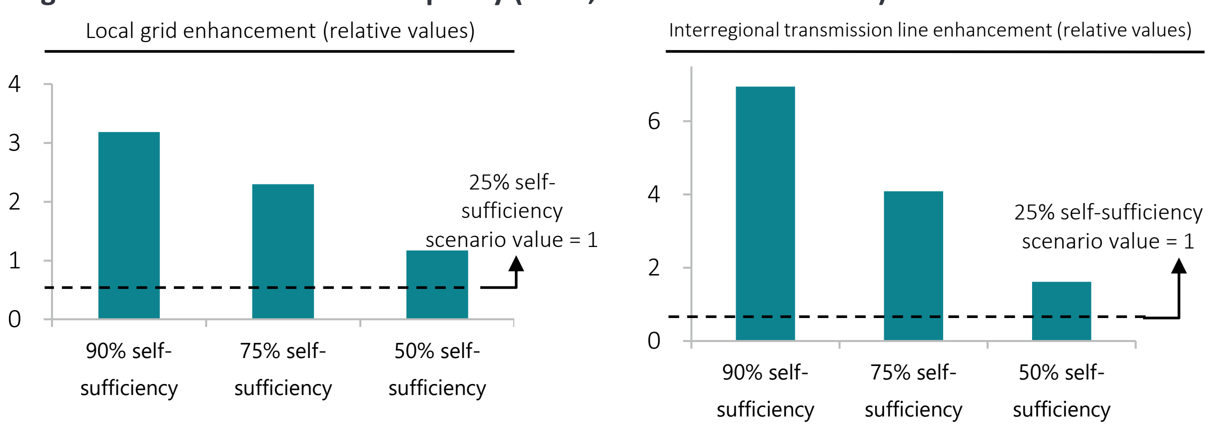


Figure 14: Grid transmission capacity (2050, units: relative values)



3.3. What are the Approaches to the Energy Transition?
- The Four Required Perspectives:
Medium-term Response: (1) Energy Infrastructure Transformation -

Introducing even more renewable energies than before will require innovations in the energy infrastructure. We need supply-demand adjustment systems across sectors and energy types, as well as regulatory reforms under the premise of demand response using digital technologies, sector coupling based on hydrogen, and an increased introduction of renewable energies.

While an increased introduction of high-capacity storage batteries, more utilization of existing pumped hydropower, and a conversion to energy carriers such as hydrogen have been advocated as ways to minimize output restrictions of variable renewable energies and make maximum use of their potential, all of these come along with issues such as high costs, limitations of the space for installation, and energy loss.

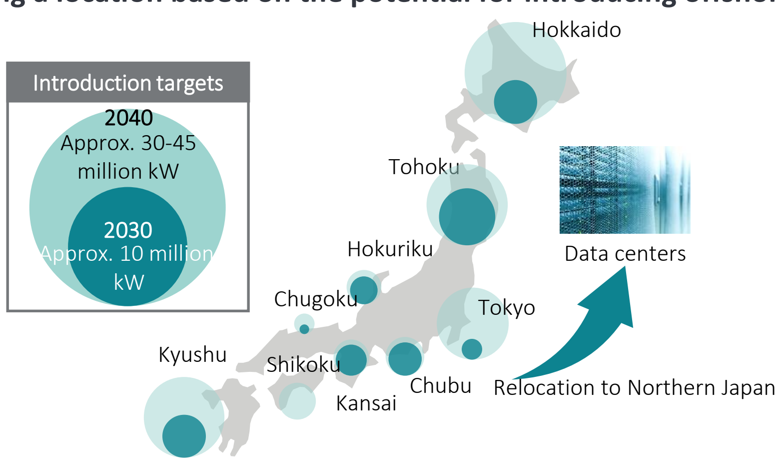
Therefore, an interchange across sectors and energy types is necessary. For example, during the time of the day when surplus renewable energy is available, power supply and demand could be balanced through the heat demand of homes and offices or the use of EV chargers while also producing e-fuel or other synthetic fuels and supply them for regional heat demand.

Moreover, until now, power plants have been operated to suit the active hours of workers, but in the future, it may be useful in terms of cost effectiveness to control industrial activities so as to suit the supply status of energy, for example, by adjusting the operation of factories with advanced automation or unmanned operation according to the power generation status of renewable energies.

Being ahead of others in terms of manpower-saving, data centers could reduce power transmission costs and the burden from supply-demand adjustments by relocating to regions with a high renewable energy potential instead of just controlling the operation time (fig. 15).

To introduce more renewable energy than before and contribute to carbon neutrality, we need supply-demand adjustment systems across sectors and energy types.

Figure 15: Selecting a location based on the potential for introducing offshore wind farms



Source: prepared by Deloitte on the basis of "Vision for Offshore Wind Power Industry (1st)," Ministry of Economy, Trade and Industry (December 2020)

A realistic approach to achieve decarbonization is to first promote the electrification of stoves, water heaters, automobiles and other appliances that rely on the direct combustion of fossil fuel. This is because, while it is possible to procure electric power originating from renewable energy even today, research on technologies such as e-fuels or methanation to substitute gasoline or city gas is underway but it is not yet clear when and how economic costs or mass production can be achieved.

Promoting electrification in this way also has the advantage that, in addition to achieving a higher energy efficiency, it becomes possible to remotely control the timing of charging or water heating and utilize these as regulating valves for the power generation status of variable renewable energies. For example, it becomes possible to level the energy demand by remotely controlling the charging time of EVs or the water heating time of electric water heaters such as EcoCute heat pump equipment (fig. 16).

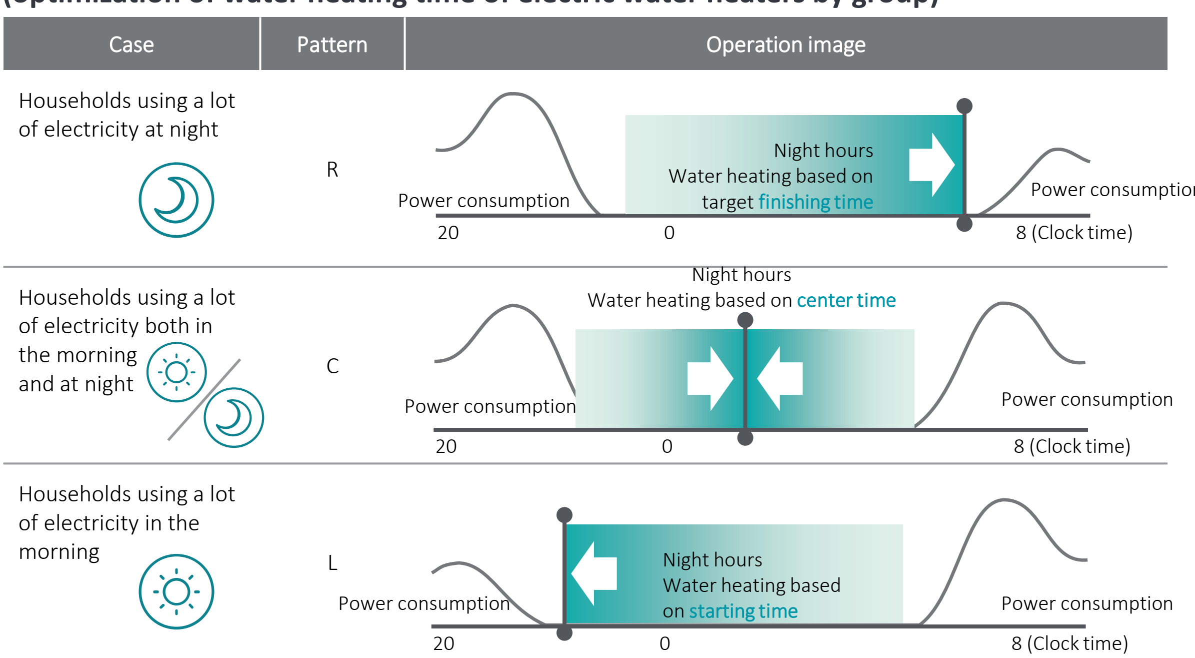
In addition to the introduction of technologies, various other measures from the institutional aspect concerning electric power systems are necessary to realize decarbonization. For grid enhancement planning and operation, a shift from individual to overall optimization is necessary. That is, the old ways under which enhancements were considered upon request from power generation operators should be changed to proactive initiatives by power transmission and distribution operators in view of the future introduction potential of renewable energies (push type wide-area grid development plan). Another measure that may become important is to use different locational marginal pricing (LMP) depending on the node to manage congestion (set a higher LMP on the over-demand side of the congested grid) by use of market mechanisms. Measures to assure adjustment capacity further include the control of demand-side equipment, EVs, and storage batteries. Maintaining the frequency of power grids by means of the inertia force of conventional power generators based on thermal power, nuclear power or the like will also be an issue for power infrastructure, since the share of these power generators will decrease in the future due to the increase of asynchronous power sources (variable renewable energy). For this reason, another important measure will be the creation of a market to trade inertia force and the introduction of smart inverters that create simulated inertia force.

The promotion of electrification is essential for decarbonization and also leads to an effective use of variable renewable energy.

Requirements for a transformation of the energy system include an efficient power grid enhancement, advanced power grid operation, and a reform of the power market.

In addition, we will need measures to deal with the decline in profitability of existing thermal power sources due to the transition from conventional centralized to decentralized power generation, and measures to optimize the kWh market and the so-called ΔkW (adjustment power) market.

Figure 16: Image of the leveling of energy demand through electrification (optimization of water heating time of electric water heaters by group)



Source: Heat Pump and Thermal Storage Technology Center of Japan, “2021 Award for Demand-side Management Control” (viewed on February 16, 2022)

The introduction of hydrogen carrier systems (using surplus electric power, etc. to electrolyze water for hydrogen production and using the produced hydrogen for mobility, industrial heat, etc.) to conventional power systems will accelerate decarbonization in the mobility and the industry sectors even more. Further, the use of existing energy-related facilities such as gas networks contributes also to an acceleration of the transition.

To achieve sector coupling including the use of hydrogen, it will, from the aspect of optimizing energy supply and demand and strengthening resilience, be important to optimize energy systems not individually but on a regional basis. Concrete examples include promoting the introduction of renewable energies together with local production for local consumption, introducing energy storage and supply-demand adjusting functions on a regional basis, and effectively utilizing waste or unused heat by the introduction of regional heating and cooling (fig. 17).

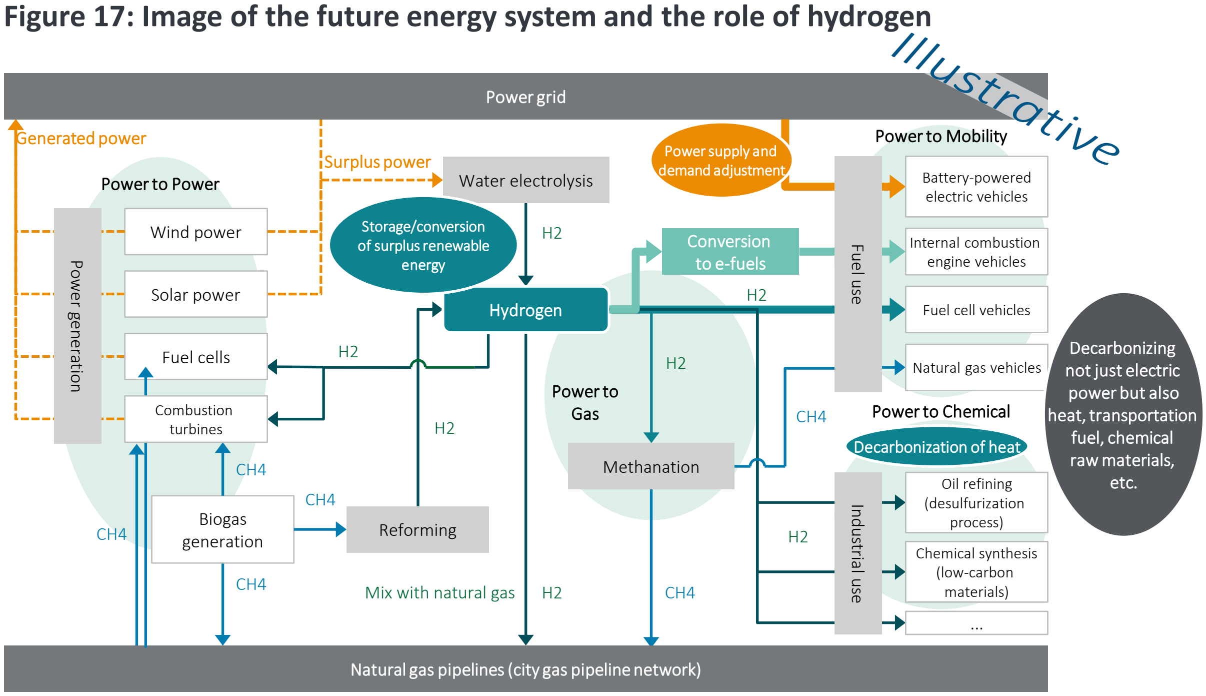
Sector coupling will contribute not just to decarbonization but also to the creation of new business opportunities. For example, the initiatives for sector coupling could trigger a strategy to increase the number of offered services while utilizing a common platform where each service (electric power, gas, etc.) used to have an own dedicated platform before. As a result, it will be possible to expand sales by offering various services while suppressing costs associated with the formation and maintenance of platforms. We believe that, in the future, conventional energy businesses will develop into a general platform business, and operators that are competitive due to higher productivity will survive. It is expected that, without sector coupling, it will be difficult to realize a business with a high profitability because it will be necessary to optimize and build a platform for each individual service.

The perspective of optimizing energy systems on a regional basis may accelerate the transition and help to solve issues on the way to the realization of sector coupling. For example, integrating multiple renewable energy sources and consumers into the system design could improve flexibility to deal with gaps between supply and demand, which is necessary to respond to the output variations caused by an accelerated introduction of renewable energies. Further, integrating multiple energy providers and consumers into the system design could help to optimize the use of surplus power or heat and thus help to deal with the necessity for more functionality to adjust the supply and demand of energy that results from the increase in prosumers. Moreover, considering and introducing the necessary functions on a regional basis helps to distribute burden and achieve economies of scale to deal with the high costs needed to set up infrastructure when new technologies are introduced.

As shown above, a perspective across the borders between individual initiatives and areas is important to achieve sector coupling and carbon neutrality.

Hydrogen is an essential energy carrier for sector coupling of different dimensions.

Figure 17: Image of the future energy system and the role of hydrogen



3.3. What are the Approaches to the Energy Transition?
- The Four Required Perspectives:
Medium-term Response: (2) Maximum Energy Savings -

To respond to soaring fossil fuel prices and contribute to carbon neutrality, it is initially effective to curb overall demand by means of efficient energy-saving measures. Also effective is a perspective of perceiving energy in terms of its quality and seeking for the optimal solution of energy as a whole, including electric power and heat.

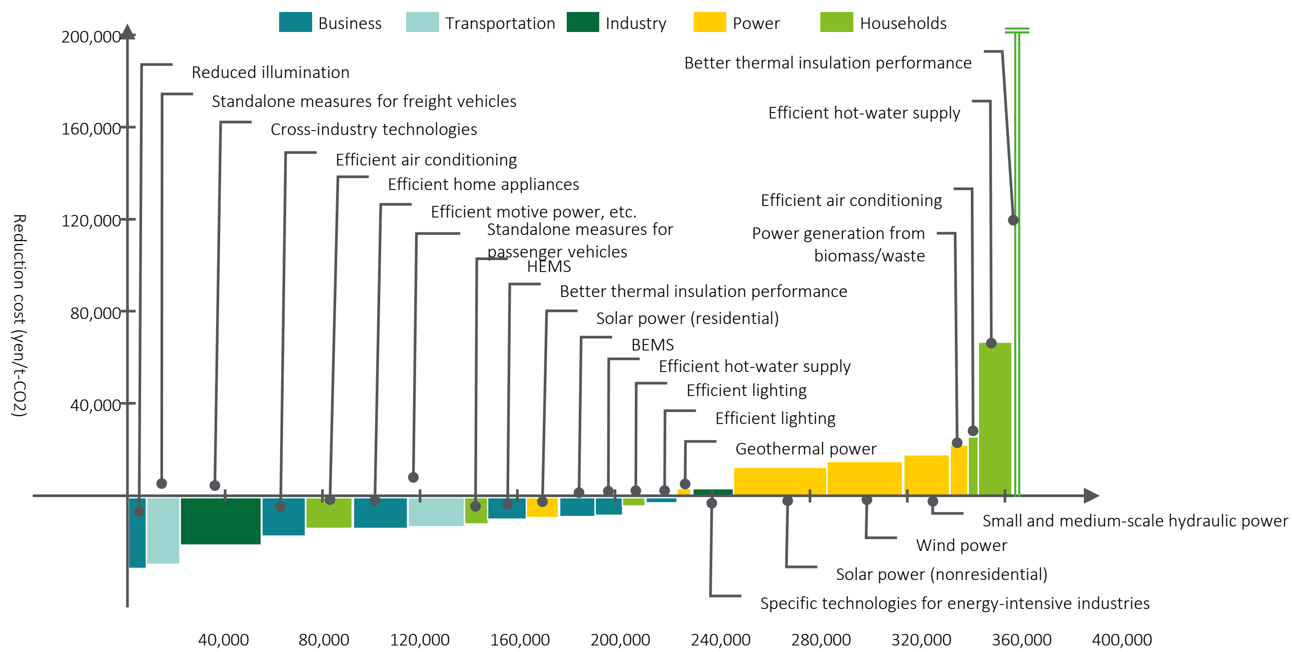
As is explained above, a maximum electrification will lead to an effective use of variable renewable energies. However, on the other hand, it may result in an increase in the total power demand. Cost assessments of decarbonization measures in Japan and other countries have revealed that energy-saving measures are more cost effective (in terms of costs for measures required to reduce CO2 emissions by 1 ton) than the development of new renewable energy sources, and it is important to promote energy-saving measures which, on a macro scale, also have a great potential to reduce CO2 emissions (fig. 19).

For example, according to an estimate by the Japanese Ministry of the Environment, equipment renewals in the business sector, such as in the automotive sector or in offices, promise to produce a significant energy-saving effect, and for this reason, it is important to have a mechanism to accelerate investments by the private sector. On the other hand, by promoting renewable energies together with electrification in, for example, water heating, which is a major CO2 emission source, a strong effect in reducing CO2 emissions can be achieved even with measures of a relatively low cost effectiveness, and it will be necessary to promote these in combination with aggressive financial measures.

Further, these measures are not limited to hardware renewals but also include energy savings through a transformation of consumer behavior and control using sensors. They are also expected to encourage the overseas expansion of Japanese companies, which have already been working on these measures for some time. Specifically, by identifying the number and locations of people in a room using infrared sensors or CO2 sensors and Radio Frequency Identifiers (RFID) it would be possible to optimize illumination and air conditioning according to the situation in which they are used.

To respond to soaring fossil fuel prices and realize carbon neutrality, it is important to curb the overall demand through efficient energy-saving measures.

Figure 19: Example of a cost-effectiveness estimate of decarbonization measures



Source: Ministry of the Environment, "A forecast for energy consumption and greenhouse gas emissions based on the discussions of the review committee on measures and strategies adopted during or after 2013"

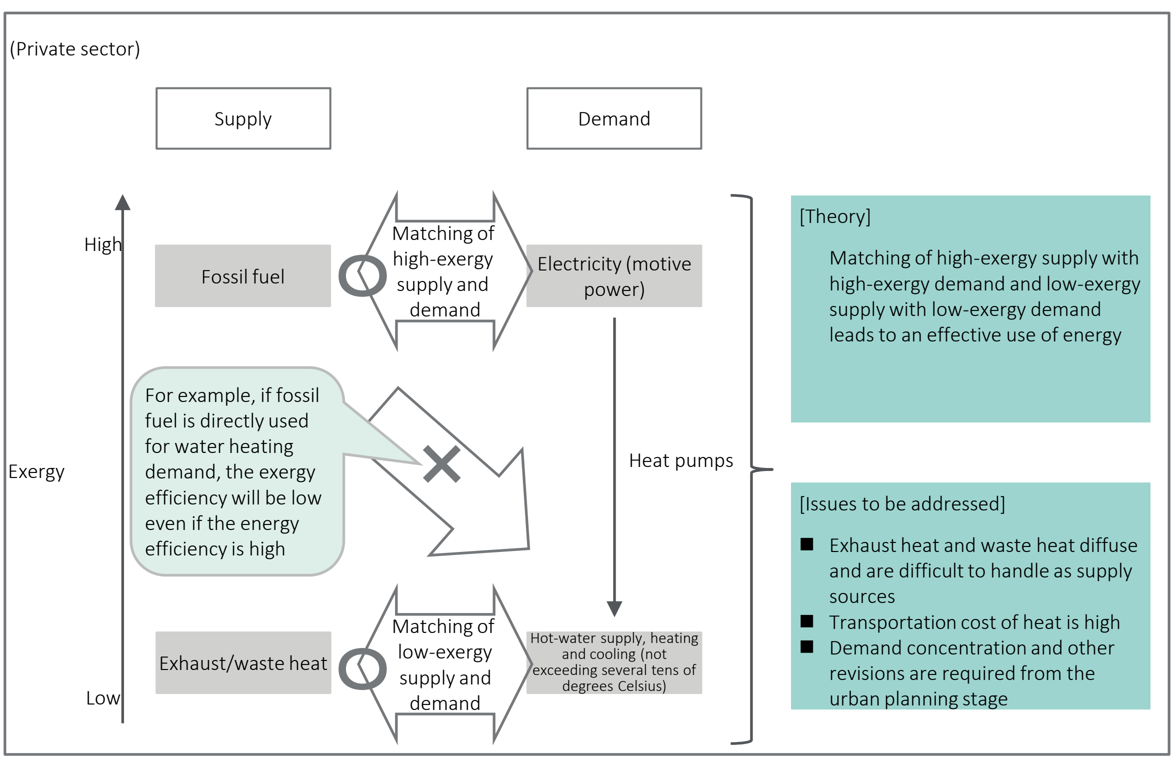
To cut unnecessary energy consumption and realize the proper use of energy in the entire society, it is necessary to look at not only the amount of energy but also its quality. To this end, it is important to match demand and supply by use of the concept of *exergy*, which is the maximum amount of energy that can be extracted as work. Specifically, it is possible to avoid a wasteful use of energy by matching high-exergy supply with high-exergy demand and low-exergy supply with low-exergy demand (fig. 20).

For example, the direct use of fossil fuel to meet demand for heat (water heating, room heating and cooling) not higher than several tens of degrees Celsius will lead to a significant loss of exergy. High-exergy fossil fuel should be used for electricity, and the demand for heat not exceeding several tens of degrees Celsius should be met by use of low-exergy energy such as exhaust heat.

Issues that need to be addressed include the high cost of heat transportation and the difficulty to handle waste or exhaust heat as a supply source because it diffuses. A solution to this could, for example, be a concentration of the energy demand, and this should be regarded as an important item to consider in urban planning from now.

To optimize an energy system that includes electric power and heat, it is necessary to consider not only the amount of energy but also its quality (exergy).

Figure 20: Matching of supply and demand on the basis of exergy



3.3. What are the Approaches to the Energy Transition?
- The Four Required Perspectives: Medium-term Response: (3) Circular Economy -

Promoting a circular economy of energy and resources will facilitate the energy transition also from the economic perspective.

To fight climate change and achieve economic growth at the same time, it is important that resources are recycled as far as possible to increase resource efficiency. In a world where output and prices of resources are becoming ever more uncertain due to geopolitical risks, this is considered to be an essential concept to ensure national and corporate resilience.

A key to successful resource recycling is to aim for an optimization of resource efficiency in the entire value chain system involving energy, by, for example, a cascaded use of energy, waste utilization, and other initiatives in addition to reducing the input of resources for energy (fig. 21).

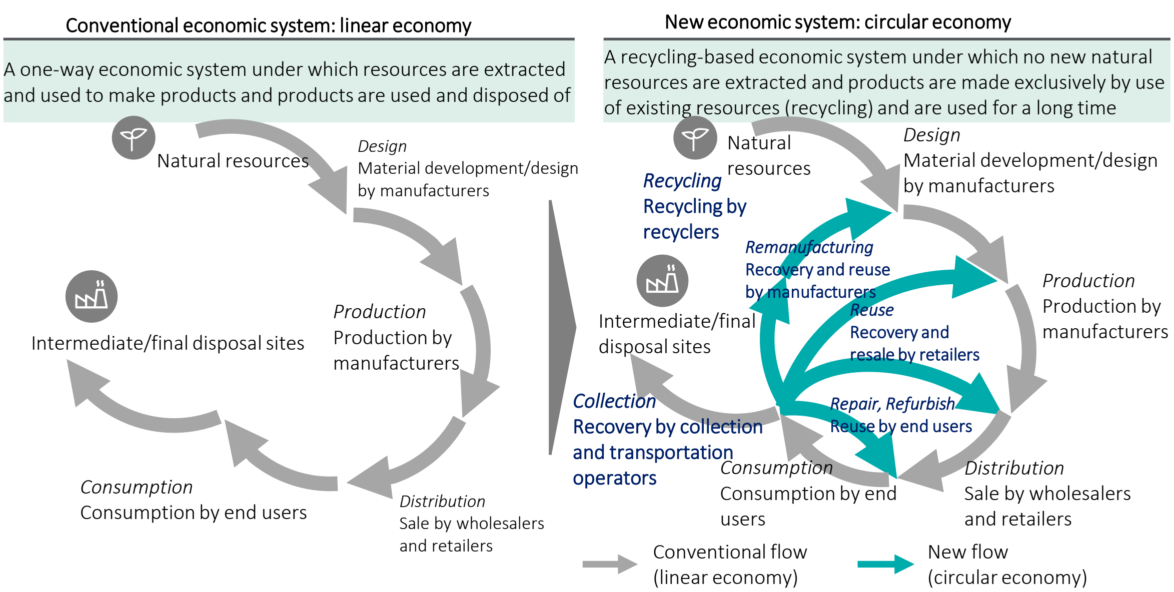
If we consider the reduction of environmental burden using the example of a supply chain in the manufacturing industry, this supply chain includes processes such as production, transportation, sales, use, and disposal. To minimize the environmental burden in this context, it is necessary to first review the use of energy within each process. Recently, there are trends to methods such as the use of biomass, hydrogen, other energy with a low environmental impact, or Carbon dioxide Capture, Utilization and Storage (CCUS), and research at various companies and institutions is underway.

Japan boasts high international competitiveness in technologies for extracting hydrogen from water using solar energy or producing plastic raw material from hydrogen and CO2.

However, just decarbonizing energy will only have a limited effect. To realize the "1.5˚C Scenario," attention should also be paid to the environmental burden caused by substances (raw materials and products). We must think about how we can continuously recycle limited resources to avoid additional burden on the environment, by, for example, using raw materials without wasting anything or using as little raw materials as possible, using finished products as long as possible, repairing them when broken, and, when no repair is possible, returning them to the manufacturer for recycling and resale.

Promoting a circular economy will facilitate the energy transition also from the economic perspective.

Figure 21: What is a circular economy?



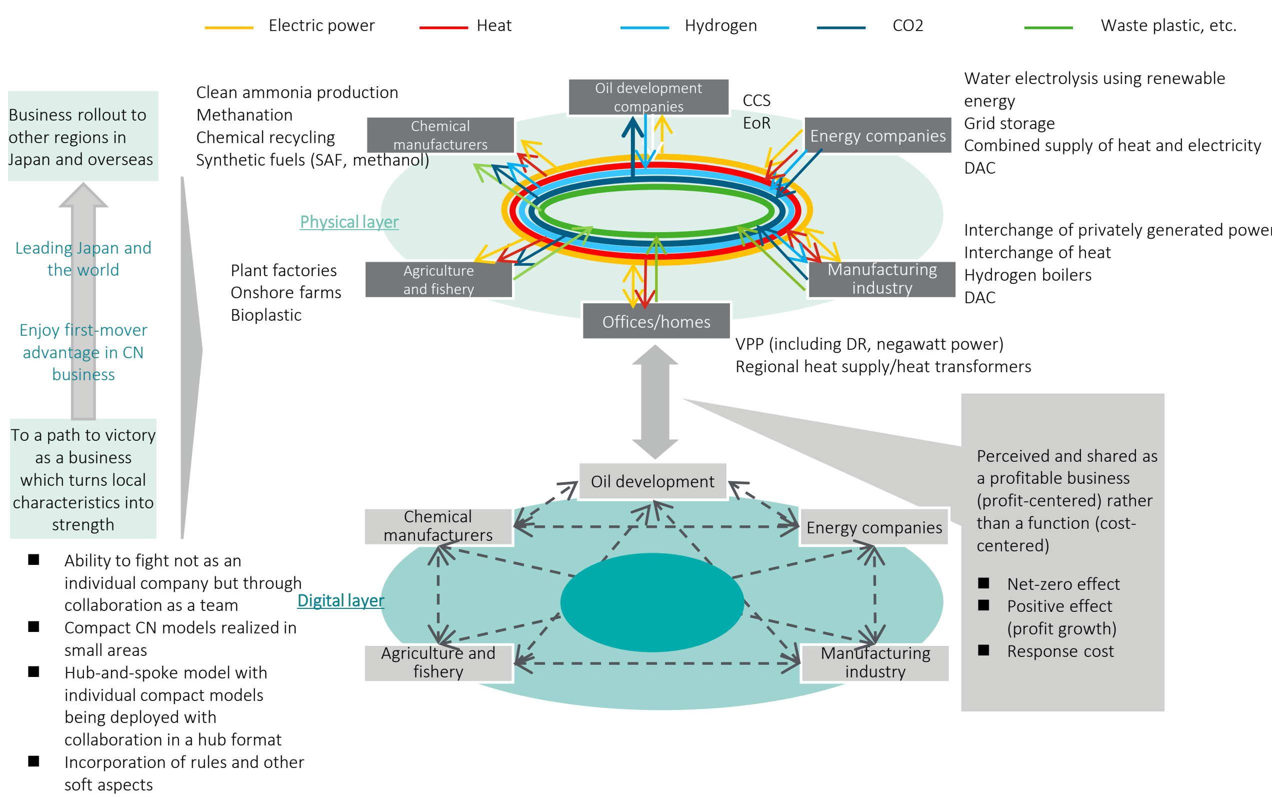
A circular economy that is an economic system under which resources are efficiently used for a long time
It is important to expand this also in the energy sector

For the system design and resource optimization of the entire value chain, it is necessary to include not just energy but also CO2 recycling. We believe that the challenge in the future will be to use CCU or other technologies to recover the CO2 having been emitted, use it as an energy resource, and optimize the energy efficiency when doing so.

Carbon neutrality cannot be achieved just by decarbonization based on an introduction of renewable energies. Initiatives that contribute to decarbonization also include energy savings to reduce the energy demand in the first place, and an energy conversion utilizing heat pumps and EVs. It will be important to combine these in an optimal way while considering the characteristics of the energy demand and the specific regions (fig. 22).

The circular economy of the energy sector needs to be composed of business that also includes an efficient recycling of CO2.

Figure 22: Promoting the transition by a circular economy



3.3. What are the Approaches to the Energy Transition? - The Four Required Perspectives: Medium-term Response: (4) International Collaboration in NETs -

The proactive introduction of NETs through international collaboration using existing cross-national cooperation frameworks as a reference will contribute to decarbonization of the entire world.

Another effective way to achieve carbon neutrality in the future are Negative Emissions Technologies (NETs). Since the locations that are suitable for NETs are unevenly distributed in the world, we believe that international collaboration is essential to use them as global resources.

A similar initiative is the Clean Development Mechanism (CDM), under which developed countries support emerging countries to reduce CO_2 emissions, and one idea would be to establish a similar framework of international cooperation also for NETs, reaching beyond the voluntary credit*[1] frame (however, since the monitoring procedures are very complicated and project registration takes a long time, it is necessary to design a system for calculations in a conservative and also simple manner).

The technology system of NETs largely consists of four categories: *Forests*, *Oceans*, *Natural weathering* and *Others*. Specific NETs falling into the category *Forests* include *afforestation/reforestation* for increasing the storage of CO_2 through more forest sequestration, *soil carbon storage* for storing carbon contained in biomass in soil, and *biochar* for storing carbon by carbonizing biomass.

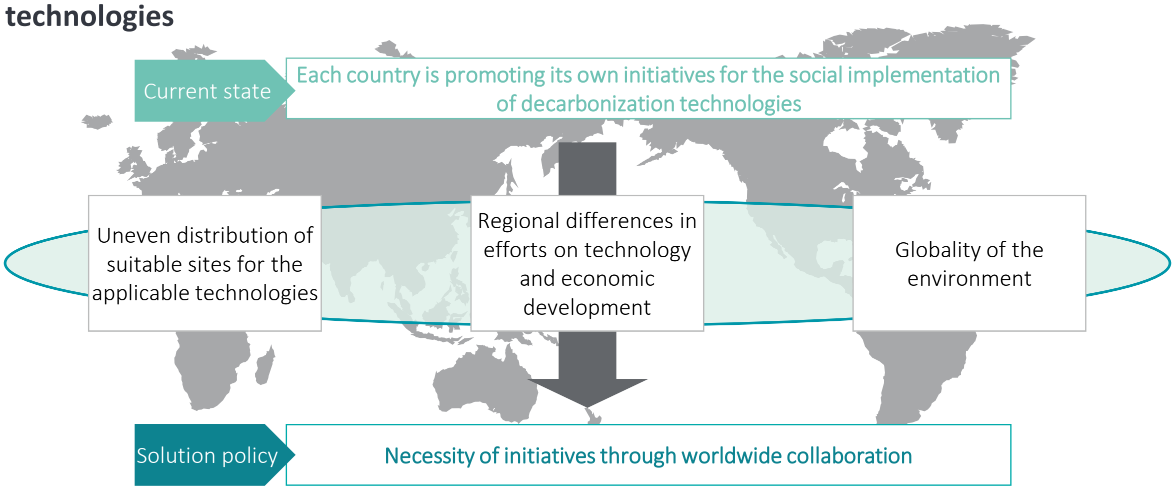
NETs of the category *Oceans* include *blue carbon* for sequestering carbon contained in plant residues in the ocean or increasing CO_2 sequestration by promoting the production of organisms in the oceans, as well as *ocean alkalinization* for increased carbon sequestration in oceans through an addition of alkaline substances to ocean water.

Natural weathering includes *enhanced weathering* for promoting the sequestration of CO_2 by artificially accelerating weathering of basalt or other minerals. NETs categorized as *Others* include industrial CO_2 underground storage.

For the category *Forests*, for *blue carbon* of *Oceans*, and for the technology for CO_2 underground storage of *Others*, the suitable locations are unevenly distributed in the world due to their physical characteristics. Further, due to the different degrees of technology development and economic development depending on the region, the commercialization of NETs is not necessarily making progress at all locations that would be suitable for NETs.*[1] In the light of these circumstances, a possible measure to achieve an expansion and marketization of NETs as an effective means to fight the global social issue of global warming could be the creation of a cooperation framework to support the introduction of NETs through worldwide collaboration instead of individual initiatives by single countries, especially when we perceive locations suitable for NETs as public resources (fig. 23).

The proactive introduction of NETs through international collaboration will contribute to decarbonization of the entire world.

Figure 23: Necessity of an international cooperative framework to spread decarbonization technologies



*1: Voluntary credit trading of emission reductions based on DACCS is already being conducted by companies including Microsoft, and the value of NETs has already been recognized

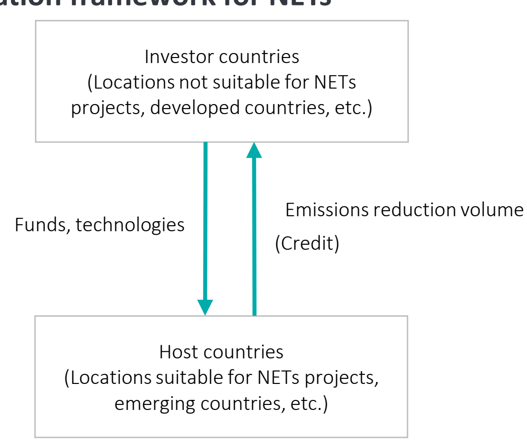
Meanwhile, NETs need to be verified with respect to their effectiveness and their impacts (especially negative impacts) other than on climate change. Therefore, research on the effectiveness of the technologies and verification to avoid that new ethical, legal, social, or other problems are caused by the introduction of NETs, needs to be carried out in the short run. Another issue is the development of methodologies for quantification of GHG reductions. Specifically, it is necessary to establish calculation and measurement methods that can be implemented by current technologies and guarantee a certain level of reliability while being consistent with the methodologies for calculating the GHG emissions in each country.

Before concretely deploying NETs projects, it is necessary to develop methodologies to quantify GHG reduction and the environmental integrity of the NETs.

Examples for existing international cooperation frameworks for promoting emission reductions and forest conservation through technology transfer and financing among nations are REDD+, which is a mechanism for emission reductions and forest conservation between developed and emerging countries, and CDM, which is a mechanism for support in reducing CO2 emissions between developed and emerging countries.

Given the uneven distribution of suitable locations for NETs, we believe that, to reduce emissions more reliably on a global scale, it is necessary to have an international cooperation framework that provides funds to NETs projects, calculates and certifies the emissions reduction effect, and is incorporated in an international emissions trading mechanism. This kind of framework could also equalize and reduce marginal emissions reduction costs of NETs (fig. 24).

Figure 24: Image of an international cooperation framework for NETs



While such an international collaboration framework for NETs has potential, it also requires advanced coordination. Issues that need to be addressed to assure market functionality and integrity include an investment scheme for fund raising, a methodology for the calculation of carbon emissions reduction and carbon sequestration volumes, and the establishment of a framework for distribution, etc. among nations. Further, international coordination and cooperation will be essential. The following lists some examples for potential solutions and issues/points to keep in mind.

- Potential fund raising solutions:
  - Raise funds by establishing a NETs fund through international institutions or international public institutions such as the World Bank and solicit contributions from participating countries and companies*1
  - Raise funds by trading the carbon emissions reduction and carbon sequestration effect of NETs through a framework including carbon credit and through emissions trading*2
- Potential solutions for the calculation and allocation of reduction/sequestration volumes:
  - Allocate the carbon emissions reduction and carbon sequestration volumes achieved by NETs projects depending on the volume of contributions by participating countries and companies. Further, provide incentives by giving some of the funds and the technology of the NETs projects to emerging countries to contribute to an international spread of NETs
- Issues and points to keep in mind for the calculation and allocation of reduction/sequestration volumes:
  - Compliance with international rules for the Joint Credit Mechanism (Article 6 of the Paris Agreement)
  - Establishment and standardization of calculation methods for carbon emissions reduction and carbon sequestration by NETs, non-permanent risk management of carbon sequestration by NETs
  - Necessity for a methodology that can be reflected in national inventories, prevention of double counting between carbon credit traders

International cooperation contributing to NETs project funding schemes, the development of methods for calculating and certifying reduction effects, and linkage to emissions trading while using existing cross-national cooperation frameworks as a reference is necessary.

*1: Examples include the Green Climate Fund (GCF) under the United Nations Framework Convention on Climate Change (UNFCCC) and the Bio Carbon Fund Initiative for Sustainable Forest Landscape (ISFL) of the World Bank
*2: Examples include Verra's Verified Carbon Standard (VCS) and the Joint Crediting Mechanism (JCM)

4. Executive Summary

In the future, an expansion of renewable energies, energy savings, a circular economy, and NETs will be necessary everywhere, and energy systems will be more complex and diversified than ever before. Therefore, we believe that these need to be considered and promoted from a systemic perspective.

- Background and Issues -

With the trend toward a carbon neutral society and the revision of energy security caused by the Ukraine crisis, the energy situation has changed dramatically. Specifically, while investments in renewable energies, clean hydrogen and other environmental technology are increasing, the prices of existing energy from coal, oil, and natural gas are rising, and there are concerns that they will stay high for some time because there is too much demand.

Moreover, considering that more and more countries are reviewing their existing transition strategies, moving up the deadlines of targets, and trying to avoid short-term risks, we assume that it will be necessary to reconsider the shape of the energy system in the long term and the transition that will be necessary in the future.

We expect that the energy systems of the future will be more complex than now, since they must take into account various evaluation indicators such as carbon neutrality, energy security, safety, and further economic growth through large-scale investment and technology development. When considering their ideal form, it will be necessary to consider factors such as technology innovation, energy decentralization, digitalization, and sector coupling.

Therefore, we believe that we need to aim for overall optimization from a *systemic perspective*, that is, we need to consider, for example, how individual initiatives affect other initiatives or the overall optimization.

- Approaches and Initiatives Necessary in the Future -

A *systemic perspective* means, for example, considering how individual initiatives affect other initiatives or the overall optimization, with overall optimization being the goal. An effective means for realizing this systemic perspective is a simulation of the entire energy infrastructure, as it can support decision-making by quantitative assessments of evaluation indicators and causes for trade-offs.

We believe that the transition necessary to achieve the long-term vision of the energy system includes the following: (1) a transformation of the energy infrastructure, (2) maximum energy savings, (3) a circular economy, and (4) international collaboration on Negative Emissions Technologies (NETs). A description of these four elements is given below.

(1) Transformation of the energy infrastructure:
Implement sector coupling while promoting electrification and a shift to hydrogen. Also promote decentralization and a regulatory reform of energy

(2) Maximum energy savings:
Energy savings through sensor-based control and changes in consumer behavior

(3) Circular economy:
Assure resource security by a circular economy, which is an economic system under which resources are efficiently used for a long time

(4) International collaboration on NETs:
Efficiently implement actions against the global issue of climate change by NETs initiatives carried out with international collaboration

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Glossary

BECCS	Acronym of Bio Energy with Carbon Capture and Storage. Technology to collect and store CO2 having been generated by combustion during the use of biomass energy
CCS	Acronym of Carbon Capture and Storage. Collection and storage of carbon dioxide
CCU	Acronym of Carbon Capture and Utilization. Collection and effective use of carbon dioxide
CDM	Acronym of Clean Development Mechanism. A CO2 emissions reduction support mechanism between developed and emerging countries
CN	Acronym of Carbon Neutrality. Achieving substantially zero emissions of greenhouse gases (GHG) overall by reducing GHG emissions while increasing their sequestration by forests and the like.
DACCS	Acronym of Direct Air Carbon Capture and Storage. Technology to directly collect and store CO2 in the air
DR	Acronym of Demand Response. Controlling electric power on the consumer side by changing power demand patterns
E-fuels	Synthetic fuels produced from electric power generated by use of renewable resources
IEA	Acronym of International Energy Agency
IPCC	Acronym of Intergovernmental Panel on Climate Change
NETs	Acronym of Negative Emissions Technologies. Also Carbon Dioxide Removal (CDR) technologies
VPP	Acronym of Virtual Power Plant. A system under which a third party (resource aggregator) or owner of power generation or storage facilities directly connected to the power grid centrally controls energy resources to provide functions similar to those of a power plant
Sector coupling	An approach to a reform of social infrastructure by linking the electric power sector with the energy consumer sector including buildings, transportation, and industry

Acknowledgements

We would like to thank Tomoya Hino and Ichiro Okura for their insights and thoughtful feedback on drafts of this report.

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