Mitsubishi Research Institute

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Social and Economic Impacts of Carbon Neutrality in 2050

Tokyo, November 4, 2022—Mitsubishi Research Institute, Inc. (MRI) has published the English version of its report featuring four scenarios for Japan's future through 2050 and calculations of the impacts of carbon neutrality on society and the economy. Based on these findings, Mitsubishi Research Institute proposes a transdisciplinary approach, coordinating policy across fields beyond just energy, to achieve a smooth transition to a decarbonized society.

The following is an overview of the report:

The shift toward longer-term decarbonization is becoming the norm

The invasion of Ukraine in February 2022 drove a sharp rise in global energy prices and brought the issue of energy security to the center stage once more. Countries across Europe have embarked on measures to address energy security, including diversifying suppliers, building up coal stores, and filling out natural gas reserves. Yet Europe is not just returning to fossil fuels. The region is working to make its energy more self-sufficient by accelerating the uptake of renewable energy and energy saving solutions; the shift toward longer-term decarbonization is in fact becoming the norm.

Globally, over 130 countries have pledged to become carbon neutral and these pledges are now being incorporated in actual business rules. Carbon neutrality will be a driver of significant structural change across society and its impacts need serious consideration—Japan is no exception.

Synergies from behavior change and technological innovation are the key to a smooth transition to carbon neutrality

A number of scenarios can be envisioned for reaching carbon neutrality. All require the maximum possible introduction of renewable energy, plus energy saving and electrification on the demand side, and will result in enormous change from the current energy supply-demand structures. In terms of the power mix, to ensure power supply and demand balancing capability to support the large-scale adoption of renewable energy, thermal power supply will have to be decarbonized as well, for example through a switch to hydrogen or ammonia fuels. The scenarios differ in the amounts of and costs for reductions to greenhouse gas (GHG) emissions. A combination of behavior changes and technological innovation will be essential to ensure a smooth transition to carbon neutrality.

Changing industry structure will affect resource circulation and HR strategies

Japan can become more energy self-sufficient through increased use of renewable energy. However, decarbonization will require more assets such as power lines, renewable energy equipment, and storage batteries. These are built with specific resources, some of which are mainly found outside Japan and in some cases in countries governed by authoritarian regimes. The markets for these materials, more so than for fossil fuels, tend to be oligopolies. Heavily reliant on other countries for assets needed in solar and wind power generation, Japan will see increased economic security risk as it transitions to carbon neutrality. Resource circulation and a circular economy will become paramount.

Decarbonization is poised to provide Japan's economy with positive effects on a national level. However, the spread will not be uniform. For example, power generation and electric equipment industries will expand but conventional automotive industries will contract; industrial structure will change significantly. A smooth transition to a decarbonized society will be based on a shift of employment into those industries in demand, with workers executing their roles in new fields. Human resource development must follow suit, taking a long-term approach to cultivate the technical and creative prowess needed for growth industries during decarbonization, such as digital talent. To minimize the negative effects of higher consumer prices, including electricity, on personal finances, the government will have to address the major challenge of how to spread the burden fairly.

Behavior change requires better information

Behavior change needs to be the first step towards decarbonization. Measures for decarbonization that are already available include switching to renewable energy or installing on-site power generation. Despite these being very effective at reducing emissions, our questionnaire survey showed that corporations and consumers remain unmotivated to take the necessary measures. Many pointed to a lack of options due to high initial costs and equipment limitations. They also reported a lack of understanding of the potential effects measures could achieve. These results indicate the potential that sufficient information and options have to promote behavior change.

Nuclear power has a role to play in harmony with renewable energy

The role of nuclear power in Japan has been in flux for over a decade. It has gained renewed interest particularly in light of recent energy market disruptions and 2030 emissions reduction targets. But the country must make clear that nuclear power will play a role in its long-term energy strategy.

Japan will need to maintain its technology and human resources, as well as innovate in nuclear power itself. Maintaining technology and human resources is important not only for safety, but also from the perspective of economic security. Innovation may lead to further improvements in safety and ways to use nuclear power in harmony with the large-scale uptake of renewable energy—prime examples including load following, hydrogen production, and heat utilization technologies. This should be accompanied by measures to alleviate the distrust of businesses related to nuclear power, such as addressing industry structure, corporate governance, and sincere stakeholder communication in particular.

Need to assume data explosion and natural disasters will happen

Gray rhino is a term to indicate something that is very likely to occur and has large effects despite often being overlooked. The data explosion already unfurling across the world is a gray rhino. As data volumes increase exponentially due to the digital transformation of society, technology needs to keep evolving so that the corresponding increase in energy consumption can be offset. Distributed system architecture needs to encompass data transmission and power generation, for example by matching additional electricity demand arising in a given region with regional power supplies such as renewable energy.

There are also concerns over how climate change will intensify storm and flood damage, plus the likelihood of megathrust earthquakes on the Nankai trough and beneath Tokyo. Japan needs to move forward with decarbonization on the assumption that such natural disasters will happen. Decarbonization of combustible energy sources, which can be easily stockpiled and transported, is an important and meaningful during both day-to-day *normalcy* and extraordinary *emergency*.

Making carbon neutrality the new Japanese competitive edge: transdisciplinary approach to be the key

Carbon neutrality will have far-reaching consequences for Japan's society and economy that will spread beyond energy-related industries. As we move toward carbon neutrality, rising demand for resources will bring new geopolitical risk and changing industrial structure will have a direct impact on employment policy. An excessive rise in energy demand due to the data explosion could also hamper both carbon neutrality and digital transformation. These issues are beyond the scope of traditional vertically organized industry and government bodies. Japan must implement programs with a transdisciplinary approach.

Japan faces numerous hurdles on the road to carbon neutrality: its current industrial structure sees manufacturing account for a relatively high share of GDP, much of the country's energy coming from thermal power generation, a lack of domestic zero-carbon energy supplies, few locations suitable for renewable energy, and frequent major natural disasters. But other countries are tackling similar challenges head on. Overcoming these obstacles will set Japan on the road to new business opportunities and competitive capabilities, and also position it to help other countries become carbon neutral. While the world has experienced a number of setbacks on the road to decarbonization, it is poised for irreversible progress over the medium and long term. Rather than being passive in the face of these waves of change, stakeholders in industry, government, and academia should work together to turn the social changes driven by decarbonization into a new competitive edge for Japan's industries.

Full Report

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1. Introduction: General outlook on carbon neutrality

Around 18 months have passed since former Prime Minister Yoshihide Suga pledged that Japan "aims to become carbon neutral by 2050" in his first policy address to Parliament in October 2020. During this time, the world has stepped up efforts to decarbonize and, as of 2022, over 130 nations and regions have committed to a timetable to becoming carbon neutral, accounting for over 90% of global GDP.[1]

Progressing from the political agenda to business rules

One event that symbolizes how the tide of decarbonization has accelerated is the 26th United Nations Climate Change conference (COP26) held in Glasgow from the end of October 2021. Discussions at this meeting went deeper than ever before and even addressed the phasing out of coal-fired power. Of particular note was the move to recognize "limiting the average temperature rise since the industrial revolution to 1.5°C" as a common goal, rather than just a target. This is only a 0.5°C difference from the 2°C target at the center of much debate, but when translated into GHG emission reductions it equates to a difference of 15 Gt-CO_2 eq/year.[2] This means additional reductions more than ten times greater than the 1.15Gt-CO_2 eq reductions made by all of Japan in fiscal 2020. Developed countries now need to submit updated emissions targets called Nationally Determined Contributions (NDCs) that are more ambitious than simply complying with the 1.5°C target, and they also need to support funding for developing nations.

The drive towards decarbonization is no longer only part of the political agenda; progress is being made to weave it into business rules and government policies (Figure 1-1). Work has started on developing rules related to financing, mostly relating to risk management, financial accounting and disclosure, and investment decisions. For trade, the EU is introducing a carbon border adjustment mechanism, with reporting obligations applying from 2023. The tide of decarbonization will wash over all industries and force through major structural changes.

Fig. 1-1: New requirements being incorporated into financial and trade rules

Financial	Risk Management	• Financial authorities recognize climate-related risks as "systemic risks" and demand financial institutions manage these risks (from January 2020)
	Financial accounting and disclosure	• Climate-related data moves from voluntary disclosure (TCFD) to obligatory disclosure
	Decisions on investment suitability	• Firming up of definitions for sustainable finance, e.g. EU taxonomy • Leading global financial institutions declared moves to achieve net-zero GHG emissions from portfolios by 2050 (GFANZ)
Trade	Carbon border adjustment mechanism	• Imports from outside EU will have prices adjusted in line with emissions • Mandatory reporting starts in 2023, mandatory payments from 2026

Source: MRI

Current energy market instability contributing to global inflation

Energy markets are in turmoil at present, and a wide gap remains between these practical problems and accelerating moves to decarbonize.

Fossil fuel prices were at record highs since mid-2021, due to the economic recovery after the pandemic and stagnant upstream investment as the world moves to decarbonize. Russia's invasion of Ukraine in February 2022 put further upward pressure on prices (Figure 1-2). WTI crude oil prices surged to the $130 mark in March 2022, the highest since 2008, and have been unstable ever since. High energy prices impact prices for

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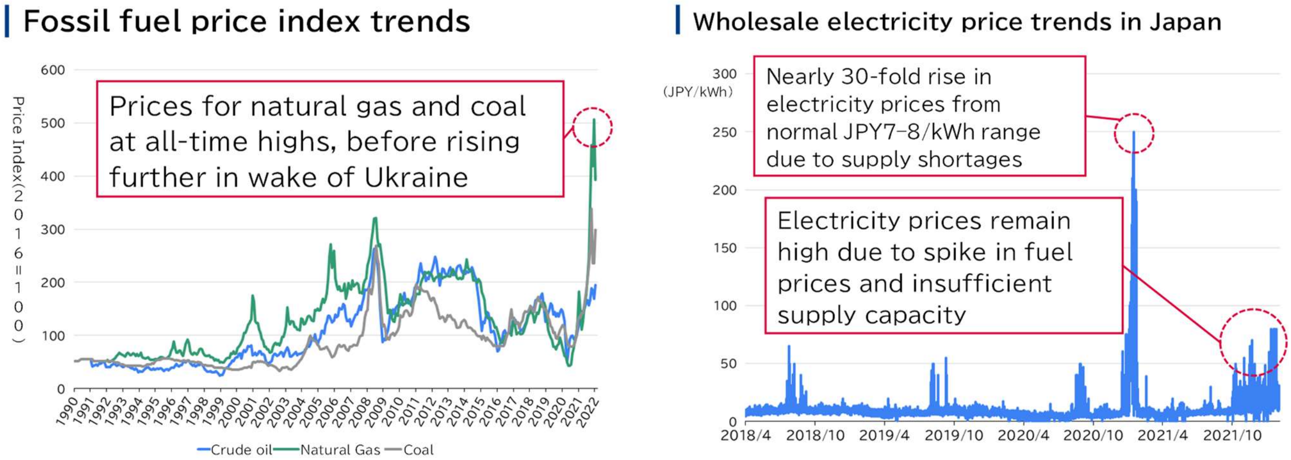
[1] Based on Net Zero Tracker, https://zerotracker.net/ (accessed on June 20, 2022), and adapted by MRI

[2] UNEP, 2021, Emissions Gap Report, https://www.unep.org/resources/emissions-gap-report-2021

everything else, so much so that since March 2021, energy prices have contributed 40% of the rise in average consumer prices in Japan, the US, and EU.

Japan has also faced significant problems from persistently high gasoline prices and wild fluctuations in wholesale electricity prices. There was a huge price spike in winter 2020 followed by wholesale electricity prices remaining persistently high during winter 2021 because of inadequate supply capacity and fuel prices. This has had a significant impact on some businesses and on consumers.

Fig. 1-2: Wild fluctuations in energy prices continue



Source: MRI, based on IMF, Primary Commodity Prices and Japan Electric Power Exchange (JEPX) data

Decarbonizing while maintaining energy security

The invasion of Ukraine has been a reminder that the old notion of energy security is still important. For example, to reduce its dependency on Russia for energy supplies, Germany is looking at diversifying what it buys, including LNG, and building up national reserves of coal and natural gas. The UK is also recognizing anew the importance of its domestically produced energy from the North Sea oilfields.

Growing awareness of energy security does not have to signify a return to fossil fuels. The REPowerEU report published by the European Commission (EC) on 8 March 2022 suggested that greater energy self-sufficiency for EU member states could actually be achieved by switching to next-generation energy, particularly renewable energy, and working on energy saving. The key here may be that over the longer term, the trend towards decarbonization will become even stronger and countries need to decarbonize while ensuring energy security at the same time.

Japan is self-sufficient for only around 10% of its energy needs, and energy security is an issue that can determine the fate of the nation. It is not easy to predict what the world will look like as far away as 2050 given the increasingly unclear outlook for world affairs and the strengthening tide of change towards longer-term, global decarbonization.

Carbon neutrality will be a driver of significant structural change across society. We must not trivialize the impacts, even in Japan, and should consider the big picture. In our recommendations on becoming carbon neutral by 2050 published in September 2021,[3] we discussed the importance of implementing specific measures at the right times: (1) changing demand-side behavior, (2) achieving net-zero emissions across the power sector at an early stage, and (3) fostering strategic innovation. This report is a further development on this theme, establishing future scenarios for Japan through 2050 and analyzing changes from the current energy supply/demand structures and the accompanying far-reaching impacts on society and the economy.

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[3] https://www.mri.co.jp/knowledge/insight/20210907.html

2. Four future scenarios through to 2050

We have established four future scenarios that take into account future uncertainties in order to analyze the social impacts of carbon neutrality in 2050. In this chapter, we discuss each scenario that form our assumptions for quantitative analysis.

2.1. Approach to setting the future scenarios

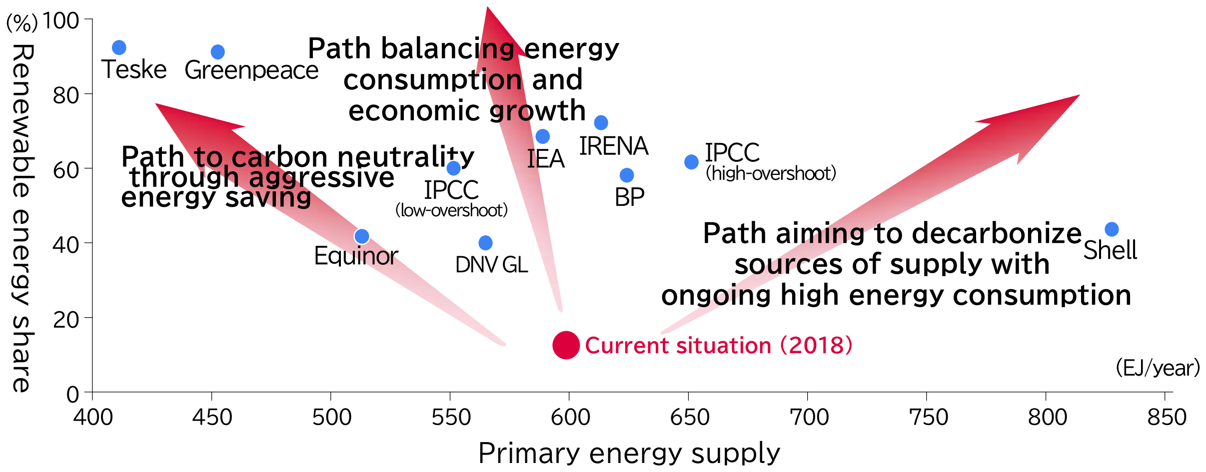
More than one pathway to carbon neutrality

Japan aims to become carbon neutral by 2050, and there are a number of possible pathways to achieving this. A number of research bodies around the world have previously analyzed energy demand structures when carbon neutrality is achieved. A comparison of the results from these analyses in terms of total primary energy supply (TPES) and renewable energy shows that there are all sorts of different ways to achieve this carbon neutral vision (Figure 2-1).

Categorizing this previous research according to specific characteristics of the scenarios, we see three types of pathway: (1) aim for decarbonization of the sources of supply while consuming lots of energy, (2) move towards carbon neutrality with an extreme focus on energy saving, and (3) achieve a balance between energy consumption and economic growth. Even though there is a common goal of carbon neutrality, there are multiple pathways depending on the assumptions for amount of energy conserved on the demand side and technological innovation on the supply side.

Fig. 2-1: Multiple pathways towards carbon neutrality

The net-zero scenarios from a number of research organizations and energy companies (global)



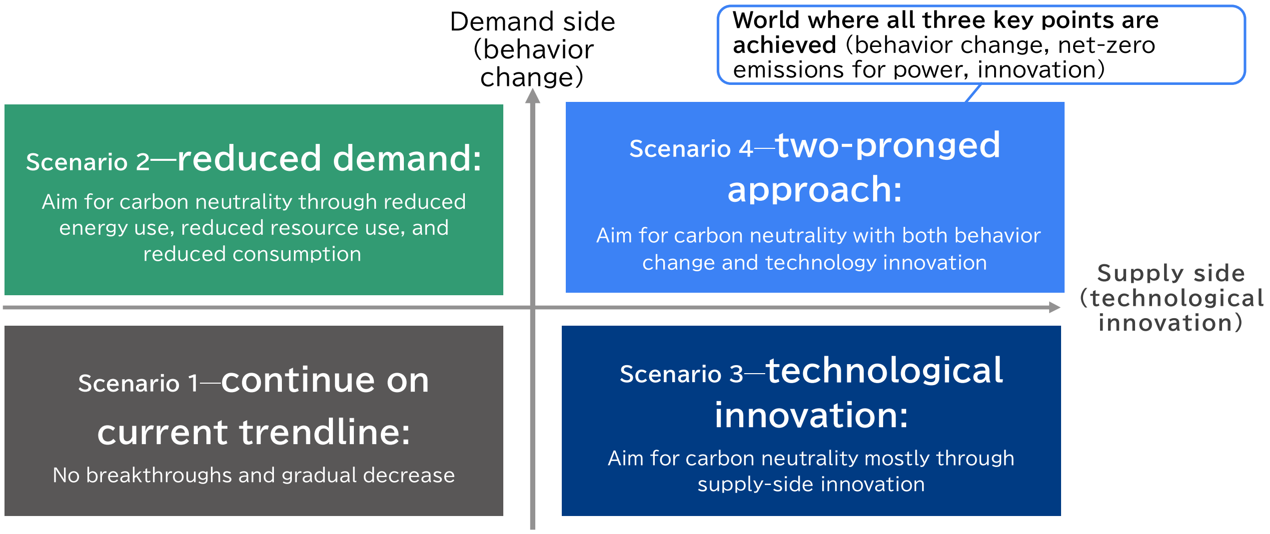
Source: MRI, from IRENA, World Energy Transition Outlook 2021

See four future scenarios for Japan based on demand × supply factors

Taking into account the trends in previous research worldwide, this report sees four possible scenarios in the future based on changing behavior on the demand side and technological innovation on the supply side (Figure 2-2).

In scenario 1, there are no breakthroughs in behavior change or technological innovation and Japan continues along its current trajectory with a gradual decrease in emissions through 2050 and does not achieve carbon neutrality. Scenarios 2 and 3 feature either behavior change or technological innovation, but not both. In scenario 2, the goal is to achieve carbon neutrality through reduced energy use, reduced resource use, and reduced consumption, but no major technological innovation. In scenario 3, there is innovation on the supply side but no behavior change, and the goal is to achieve carbon neutrality with energy consumption continuing at high levels. Finally, in scenario 4, the world reaches carbon neutrality through both behavior change and technological innovation. In this last scenario, we assume progress worldwide in all of the three key points described in our 2021 report on recommendations for becoming carbon neutral by 2050: (1) changing demand-side behavior, (2) achieving net-zero emissions across the power sector at an early stage, and (3) fostering strategic innovation.

Fig. 2-2: Four scenarios based on demand-side behavior change and supply-side technological innovation



Source: MRI

2.2. Global perspectives on the four future scenarios

Scenario 1—continue on current trendline: No breakthroughs and gradual emissions decrease

Scenario 1 simply extends the current trendline through to 2050. None of the three key points are achieved and carbon neutrality is not reached by 2050. Real GDP growth through 2050 is +0.01% per annum and the reductions achieved in 2050 versus 2013 are only −34% for final energy consumption and −48% for GHG emissions.

Three key points achieved?

Behavior change	No
Net-zero emissions for power	No
Innovation	No

Real GDP growth (average for 2022–50)	+0.01%
Final energy consumption (versus 2013 levels)	-34%
% reduction in GHG emissions (versus 2013 levels; before CCUS)	-48%

➡ Carbon neutrality not reached

Scenario 2—reduced demand: Aim for carbon neutrality through reduced energy use, reduced resource use, and reduced consumption

Under scenario 2, the world aims to achieve carbon neutrality through reduced energy use, reduced resource use, and reduced consumption. Of the three key points, this scenario achieves behavior change and some progress is made towards net-zero emissions for power, but there is no major technological innovation. Real GDP growth through 2050 is −0.13% per annum and the reductions achieved in 2050 versus 2013 are −50% for final energy consumption and −83% for GHG emissions, with carbon neutrality reached using negative emissions.

Three key points achieved?

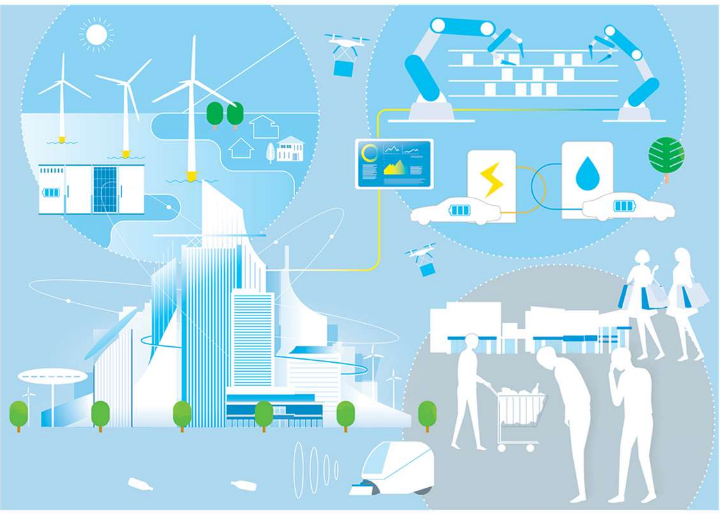
Behavior change	Yes
Net-zero emissions for power	Some
Innovation	No

Real GDP growth (average for 2022–50)	-0.13%
Final energy consumption (versus 2013 levels)	-50%
% reduction in GHG emissions (versus 2013 levels; before CCUS)	-83%

➡ Carbon neutrality reached using negative emissions

Scenario 3—technological innovation: Aim for carbon neutrality mostly through supply-side innovation

Under scenario 3, technological innovation is used to achieve carbon neutrality with no change in mass-consumerism. Of the three key points, net-zero emissions for power and innovation occur, but there is no change in behavior. Real GDP growth through 2050 is +0.10% per annum and the reductions achieved in 2050 versus 2013 are −48% for final energy consumption and −89% for GHG emissions, with carbon neutrality reached using negative emissions.



Three key points achieved?

Behavior change	No
Net-zero emissions for power	Yes
Innovation	Yes

Real GDP growth (average for 2022–50)	+0.10%
Final energy consumption (versus 2013 levels)	-48%
% reduction in GHG emissions (versus 2013 levels; before CCUS)	-89%

➡ Carbon neutrality reached using negative emissions

Scenario 4—two-pronged approach: Aim for carbon neutrality with both behavior change and technology innovation

Scenario 4 sees carbon neutrality achieved through a two-pronged approach of simultaneous behavior change and technology change. All three of the key points are achieved; this is the society we should be aiming for. Real GDP growth through 2050 is +0.06% per annum and the reductions achieved in 2050 versus 2013 are −54% for final energy consumption and −90% for GHG emissions, with carbon neutrality reached using negative emissions.

Three key points achieved?

Behavior change	Yes
Net-zero emissions for power	Yes
Innovation	Yes

Real GDP growth (average for 2022–50)	+0.06%
Final energy consumption (versus 2013 levels)	-54%
% reduction in GHG emissions (versus 2013 levels; before CCUS)	-90%

➡ Carbon neutrality reached using negative emissions

Parameters set for each scenario

We set specific parameters for the macro framework, activity levels, and supply-side technologies based on a global perspective for each scenario (Figure 2-3). For the macro framework, we used the same parameters for population and number of households in all four scenarios, and we derived real GDP from the results of economic and employment analyses described below.

In scenario 1, we set parameters for activity levels and supply-side technologies that represent an extension of the current trend line. For scenario 2, we adjusted activity levels in the various demand sectors to reflect change due to the sharing economy, circular economy, and digitalization. For scenario 3, we set parameters that expressed technology innovation in renewable energy, hydrogen, and the steelmaking and automotive fields. Under scenario 4, the parameters reflected the outcomes from simultaneous behavior change and technology innovation as seen in scenarios 2 and 3. See the Appendix at the end of this report for details on the parameter settings.

Fig. 2-3: Specific parameters based on a global perspective for each scenario

World aiming for carbon neutrality

		Scenario 1: current trendline	Scenario 2: reduced demand	Scenario 3: technological innovation	Scenario 4: two-pronged approach
Macro framework		Same population, household numbers used in all scenarios; real GDP calculated using results of economic/employment analyses (same figures for GDP used as basis for calculations of service demand); fuel prices set based on assumptions from World Bank (Commodity Price Forecast)			
Activity levels (service demand)	Industry	At current trendline	Advances in sharing economy, circular economy leads to reduction in both final products and materials	Like scenario 1. However, for steel, Japan leverages its competitive edge in carbon-neutral technologies to grow exports	Simultaneous progress in both scenarios 2 and 3
	Commercial	At current trendline	More remote work leads to decline in offices, increase in households Earlier uptake of more efficient products as replacement with energy-saving equipment accelerates	Like scenario 1. However, move to more efficient equipment due to technological innovation (rate of uptake is like scenario 1)	
	Transportation	At current trendline	Aggressive introduction of digital technologies leads to fewer passengers, increased freight	Same as scenario 1	
Power	Electricity demand, thermal power	Calculated as part of the model			
	Nuclear power	Same for all scenarios (only operate plants compliant with new standards; no expectation for newly built capacity, replacements)			
	Renewable energy	At current trendline	At level of government investigations	Further uptake of next-generation renewable energy (e.g., perovskite solar cells) Increases % of domestically produced energy procurement	
Hydrogen use		Competitive hydrogen technologies not developed		Cheap hydrogen imports possible (JPY20–30/Nm³)	
Steel		No innovative technologies, continue with existing steelmaking methods		Successful development of hydrogen direct reduction (H-DR) method for steelmaking, possible to replace blast furnaces	
Automotive		Costs for next-generation vehicles remain low No development of alternative decarbonized technologies for long-distance transportation		Roughly the same cost levels for EVs, FCVs as for gasoline-powered vehicles, leading to FC technologies being used for long-distance transportation	

Source: MRI

3. Structural changes brought about by carbon neutrality

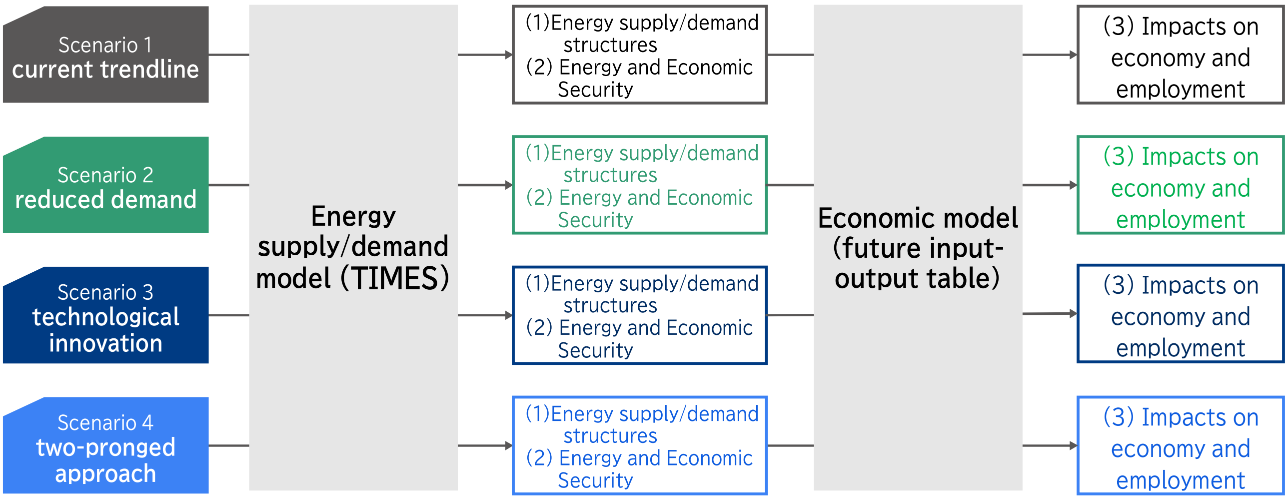
In the previous chapter, we described four scenarios for Japan. The next question then is what will the world be like under each scenario—what will be the same and what will be different? In this chapter, we use a proprietary energy supply/demand model (TIMES) and an economic interindustry relations model (future input-output table) to develop a quantitative vision for (1) energy supply/demand structures, (2) energy and economic security, and (3) the economy and employment.

Figure 3-1 shows the specific analytical flow. First, we input into the TIMES model the parameters (macro framework, activity levels, supply side technologies etc.) set for each scenario based on a global perspective. The TIMES model uses a back-casting approach to analyze the energy supply/demand structures for all of Japan, not just the electricity sector. Sections 3.1 and 3.2 shows our analysis of energy supply/demand structures and energy and economic security based on the TIMES output.

Next, in order to analyze the impact that changes in energy supply/demand structures have on the economy and employment, section 3.3 shows the future input-output tables created for each scenario and analysis of the economic ripple effects based on the results from TIMES. Specifically, we produced an input-output table (future input-output table) by adjusting input and output structures between coordinated industries in line with each scenario, and then calculated the economic ripple effects (output, value added, and employed population). Note that we assume economic ripple effects through to secondary ripple effects.

For details of the TIMES model and interindustry relations analysis, see the Appendix at the end of this report.

Fig. 3-1: Quantification of the social impacts of carbon neutrality using an energy supply/demand model (TIMES) and economic model (future input-output table)



Source: MRI

3.1. Impact on energy supply/demand structures

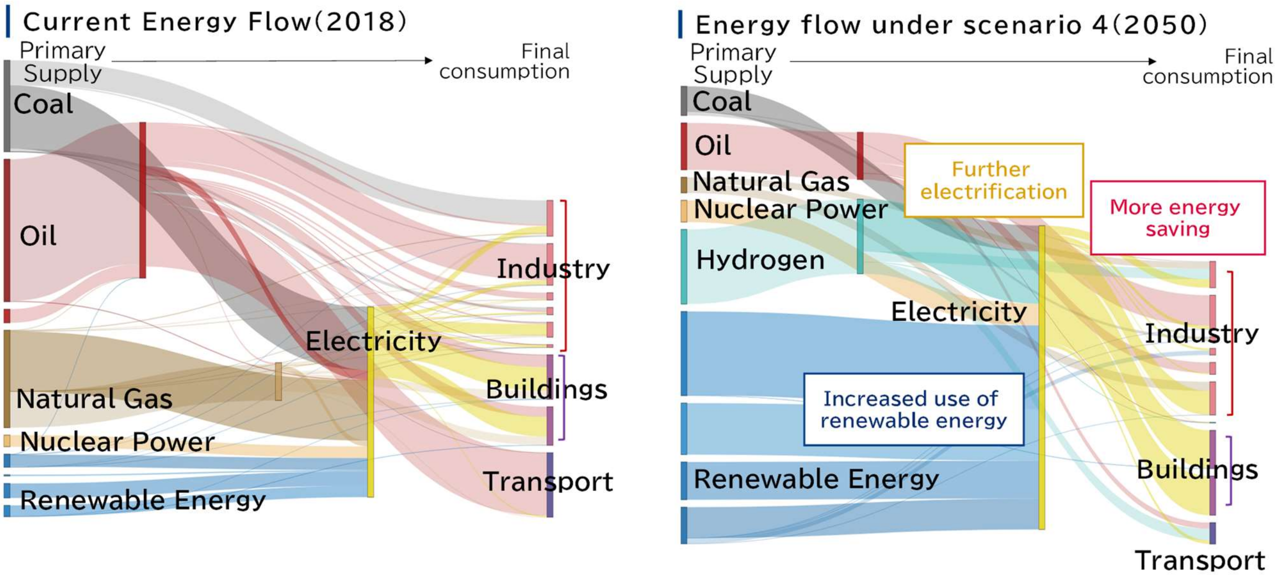
In this section, we discuss the key points for what energy supply/demand structures will look like when carbon neutrality is reached, and analyze each scenario for commonalities and differences.

Energy supply/demand structures will be very different from today

As we approach carbon neutrality in 2050, energy supply/demand structures will be very different from today (Figure 3-2). We highlight three major features in the changes to supply/demand structures.

First, the main supply structures will change to decarbonized energy, mostly renewable energy. At present, fossil fuels account for over 80% of primary energy supplies, but under scenario 4 decarbonized energy will account for 80% of the total. Next, there will be enormous progress in energy saving on the demand side. Final energy consumption under scenario 4 will be around half of current levels. There will also be significant progress in electrification of energy demand. At present, electric power accounts for 26% of final energy consumption (electrification rate), but this will roughly double to 52% in 2050.

Fig. 3-2: Energy supply/demand structures will be very different from today when we reach carbon neutrality



Source: MRI estimates; actual figures taken from Total Energy Statistics from the Agency of Natural Resources and Energy
Vertical axis: 100% = total primary energy supply

Scenarios that achieve carbon neutrality all share some common themes

While there are multiple pathways to achieve carbon neutrality, analysis of the energy supply/demand structures in scenarios 2, 3 and 4 (where carbon neutrality is achieved) shows some common themes.
First, decarbonized energy as a percentage of primary energy supply is around 70–80% in these scenarios where carbon neutrality is achieved and renewable energy forms the main energy supply for all three scenarios (Figure 3-3). These scenarios also feature substantial progress in energy saving and electrification on the demand side, with all three scenarios showing a halving in final energy consumption and a doubling in electrification rates versus current levels (Figure 3-4).

Renewable energy accounts for around 70% of the energy source mix for scenarios 2, 3 and 4, and this will require electric power systems to be able to balance power supply and demand as renewable energy becomes the main power source in the mix. Evaluations using our MRI power source model[4] show that thermal power supplies would still account for 30% even assuming increased use of storage batteries and expansion of the electric power system (Figure 3-5). This suggests that another essential element in achieving carbon neutrality will be decarbonizing thermal power sources, for example through the use of hydrogen or ammonia power generation, for use in power supply and demand balancing.

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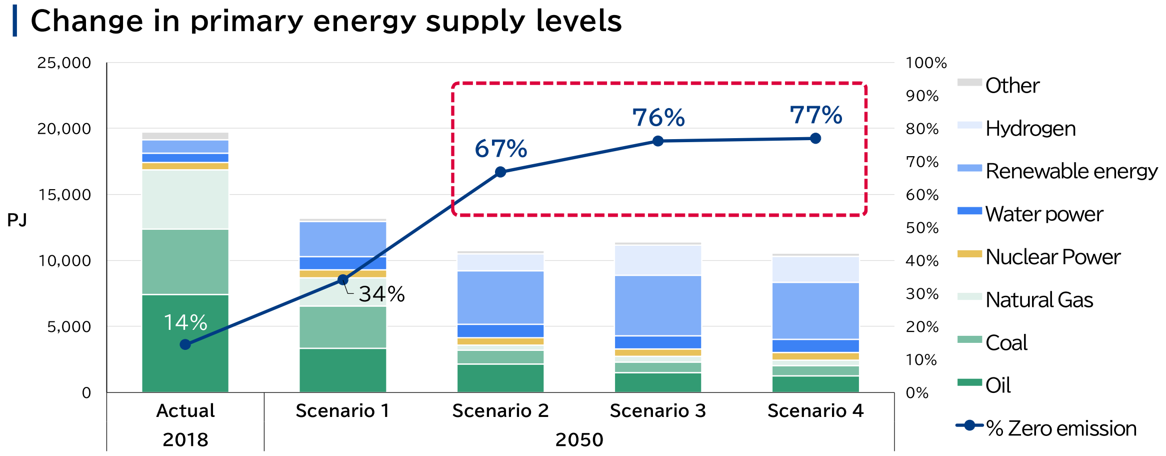
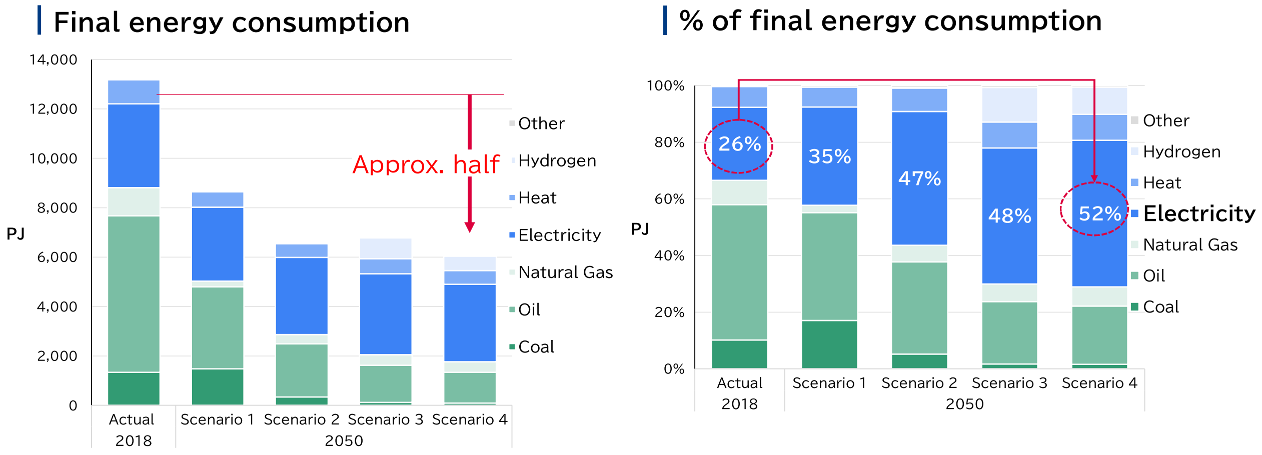
[4] Wide area simulation model that matches supply and demand in 60-minute units by region with restrictions on interconnectors

Fig. 3-3: Renewable energy becomes the main source in primary energy supply structures


Change in primary energy supply levels

Source: MRI estimates; actual figures taken from Total Energy Statistics from the Agency of Natural Resources and Energy

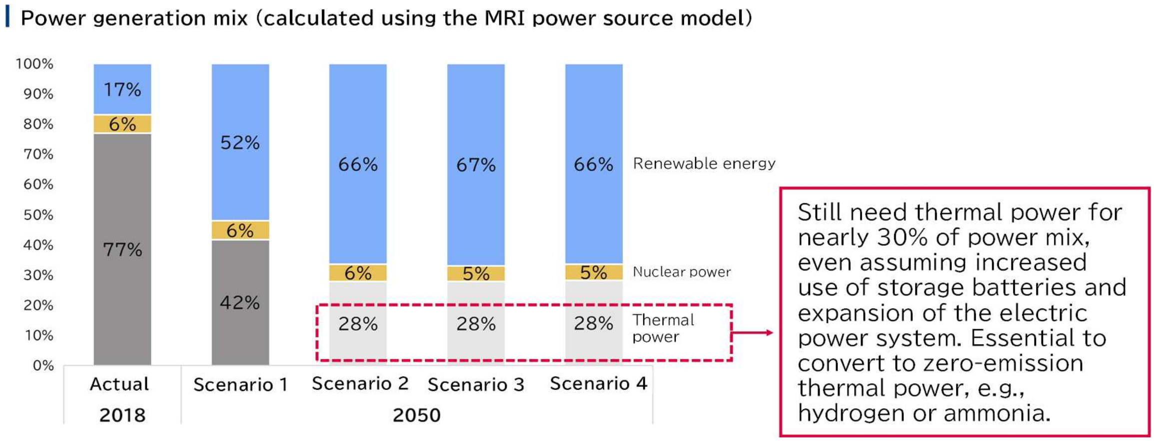
Fig. 3-4: Substantial progress on the demand side in energy saving and electrification


Final energy consumption

% of final energy consumption

Source: MRI estimates; actual figures taken from Total Energy Statistics from the Agency of Natural Resources and Energy

Fig. 3-5: Thermal power sources must become zero emission


Power generation mix (calculated using the MRI power source model)

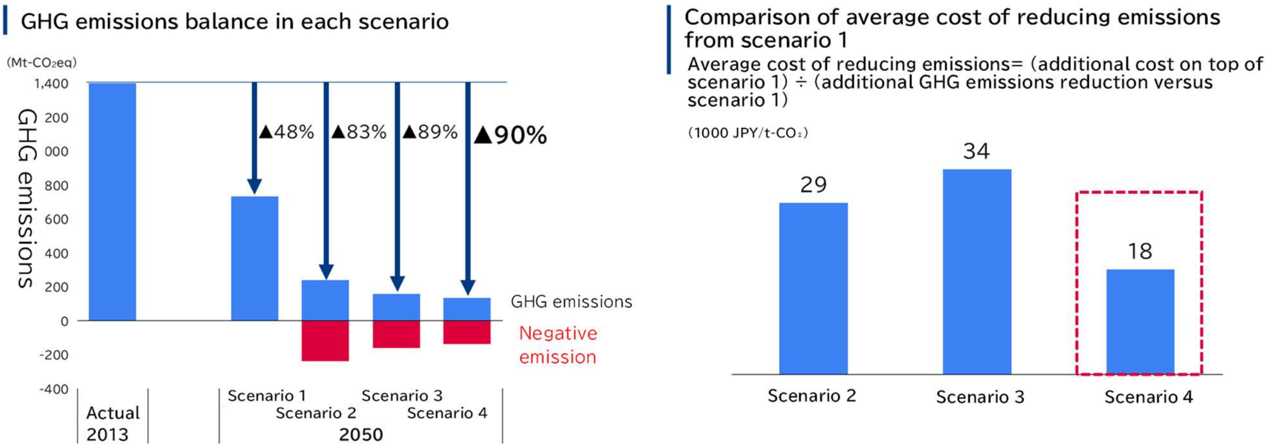
Still need thermal power for nearly 30% of power mix, even assuming increased use of storage batteries and expansion of the electric power system. Essential to convert to zero-emission thermal power, e.g., hydrogen or ammonia.

Source: MRI estimates; actual figures taken from Total Energy Statistics from the Agency of Natural Resources and Energy

Achieving carbon neutrality through two-pronged approach of behavior change and technological innovation

Having discussed the common themes in the scenarios that achieve carbon neutrality, let us now turn to the differences between these scenarios. From the perspective of emissions reductions, we can see that the combination of behavior change with technological innovation in scenario 4 generates synergies. Scenario 4 has the highest % reduction in GHG emissions before negative emissions at 90% below 2013 levels (Figure 3-6). This means that a lower level of negative emissions is needed to achieve carbon neutrality. Scenario 3 with its focus on technological innovation achieves similarly high levels of GHG emissions reductions, but a comparison of the average cost of reducing emissions shows that the two-pronged approach in scenario 4 is the cheapest. This suggests just how important it will be to combine behavior change with technological innovation to reach carbon neutrality.[5]

Fig. 3-6: Synergies from behavior change and technological innovation in scenario 4



Source: MRI estimates; actual GHG emissions figures taken from National Institute for Environmental Studies greenhouse gas inventory data

Note: For scenario 3 the average cost of reducing emissions is higher, but because the technological innovation may result in a competitive edge in industry the overall economic impact may not be negative. The above figure shows a comparison of the costs to reduce gross emissions before negative emissions.

3.2. Impact on energy and economic security

We need to think differently about energy and economic security once we are living in a carbon neutral society. In this section, we reflect on the results of the analyses in section 3.1 and conduct further analysis from a security perspective.

New phase of economic security in a carbon neutral society

For Japan with its lack of fossil fuel resources, the rise of decarbonized energy (i.e., renewable energy and nuclear power) will help make the country more energy self-sufficient. Japan is currently self-sufficient for around 20% of its energy needs, but our analysis shows this would improve to around 60% under the scenarios where carbon neutrality is achieved (Figure 3-7). However, Japan is heavily reliant on other countries for the materials needed for renewable solar or wind power, so we also need to consider technology self-sufficiency that factors in domestic procurement. Technology self-sufficiency may not improve as much as energy self-sufficiency if Japan cannot increase the percentage of domestic procurement at the same time as improving energy self-sufficiency.

Other important factors are the resources needed to build decarbonized energy systems and the different characteristics compared with fossil fuel resources. Decarbonized energy tends to be low density and dispersed, so these types of energy systems use much more by way of resources than energy-dense fossil fuels. The resources needed for power lines or for renewable energy and storage batteries are only found in some geographic regions that tend to be under the control of authoritarian regimes and these markets are more of an oligopoly than for fossil fuel resources (Figure 3-7).

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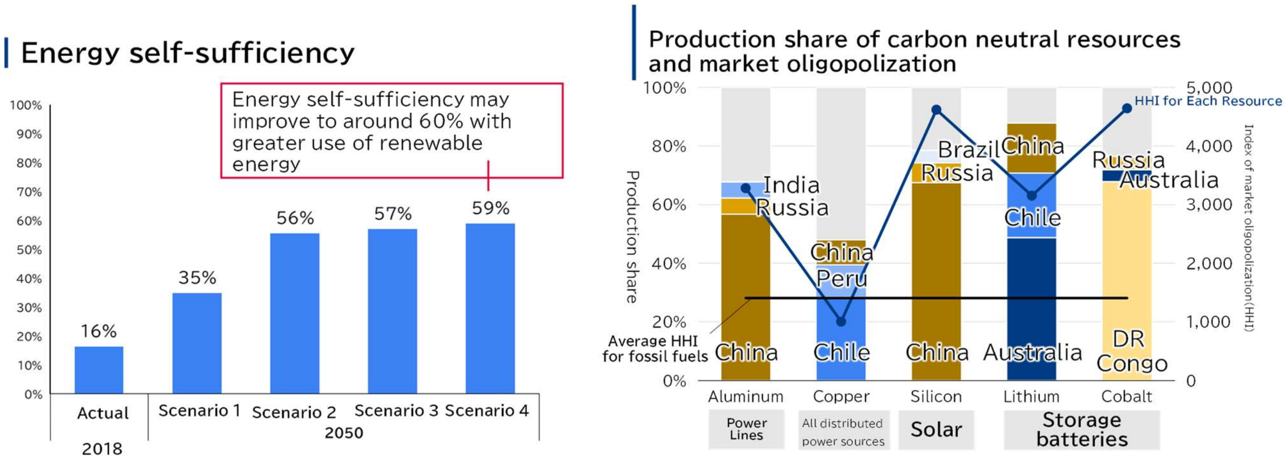
[5] In addition, a comparison of the cumulative GHG emissions through 2050 under scenarios 3 and 4 shows that scenario 4 results in higher emissions reductions because it is feasible to achieve demand-side behavior change at an earlier stage.

While there may be different timeframes for the risk of interruptions to energy supplies and to materials and resource supplies, our analysis suggests that we need to think differently about energy and economic security in terms of the energy systems we need to build for a decarbonized society.

Fig. 3-7: Need to think differently about security in a carbon neutral society



Source: (Left) MRI estimates, (right) MRI, from the U.S. Geological Survey, Mineral Commodity Summaries and BP, Statistical Review of World Energy 2021[6]

Resource constraints will accelerate moves to circular economy

As discussed above, to build a decarbonized society, one extremely important discussion point is how to secure stable supplies of the resources needed in large quantities but that are unevenly distributed in geographic terms. As concerns mount over emerging resource constraints, the drive to carbon neutrality may spur the development of a circular economy. Moreover, we anticipate a transition to a recycling-oriented society even as a way to trial reductions in carbon burden (Figure 3-8).

For metal resources, we may see a shift to an industrial structure based on the supply and use of secondary resources[7] because of the uncertainties over stable supply in the future and the pursuit of maximum efficiencies for sustainable resource use. If metal prices surge because of resource constraints and carbon pricing, secondary resources may become more price competitive than natural resources.

In addition, because plastics emit CO_2 when incinerated, we expect a switch to alternative materials and more recycling to avoid incineration. Traditional industries will come under pressure to completely change direction as societies become increasingly decarbonized in pursuit of carbon neutrality—a good example is naphtha, which is the primary raw material used to make plastics and a byproduct of oil refining. We therefore expect carbon neutrality to be the starting point for an acceleration in the development of a circular economy, with supply chain structures becoming increasingly important and discussions on how to build a decarbonized society more multidimensional.

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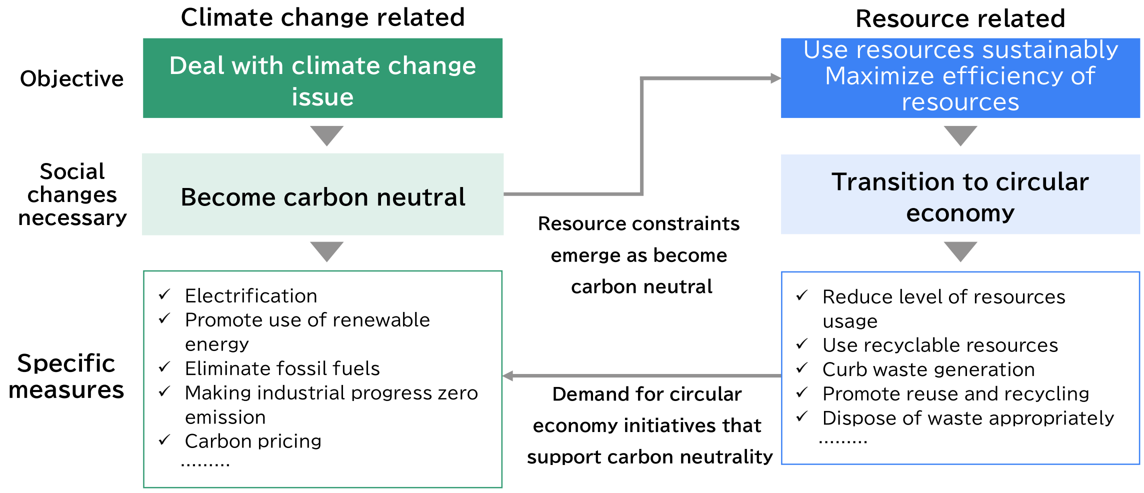
[6] HHI: The Herfindahl-Hirschman Index is calculated from the square of the top three countries' share. Yellow shows authoritarian nations and blue shows democratic nations. Classification as authoritarian or democratic references the Economist Intelligence Unit (EIU).

[7] Resources that can be used after recycling used products

Fig. 3-8: Resource constraints with carbon neutrality may accelerate development of a circular economy



Source: MRI

3.3. Impact on industry, employment, and household finances

The shift to carbon neutrality will not only affect energy supply/demand structures. It will also have major impacts right across industry. In this section, we use the interindustry relations analysis discussed above to investigate impacts on industry, employment, and household finances.

Decarbonization will have both positive and negative impacts on industry

To investigate the change in industrial output and value added as society decarbonizes, we compared scenario 4 (two-pronged approach of behavior change and technology innovation) with scenario 1 (continue on current trendline). Looking at the overall picture with these two scenarios, scenario 4 shows industrial output at ¥19.6tn higher and value added at JPY8.1 trillion higher than with scenario 1 (direct effects + primary ripple effects + secondary ripple effects), indicating that the two-pronged approach in scenario 4 has a positive impact on the economy

By industry, however, the results showed some industries expand while others contract as society decarbonizes (Figure 3-9) and that industrial structure will undergo significant change.

Electric power-related businesses are of particular interest as an expanding industry. Under scenario 4, the negative effects from thermal power generation were far outweighed by the positives from renewable energy and hydrogen power generation industries. We expect substantial ripple effects in industries working in the construction of electrical equipment and facilities for the transmission of existing electricity supplies, the construction of facilities for solar power and wind power and the component parts needed. Our analysis showed a boost to value added for electronic components, electrical machinery, and general-purpose machinery, because the calculations include machinery for offshore wind power equipment and the like.[8]

The automotive industry is a prime example of an industry that will contract. While there will obviously be positive ripple effects from the transition to EVs and FCVs, this will be outstripped by the negative impacts on existing car manufacturing, automotive parts, and automotive internal combustion engine businesses, which will produce a significant downturn in value added.[9] We also expect substantial negative ripple effects on other industries, including petroleum and coal products and steel-related industries [pig iron or crude steel (rotary kilns)] as hydrogen direct reduction (H-DR) steelmaking and electric furnaces are rolled out.

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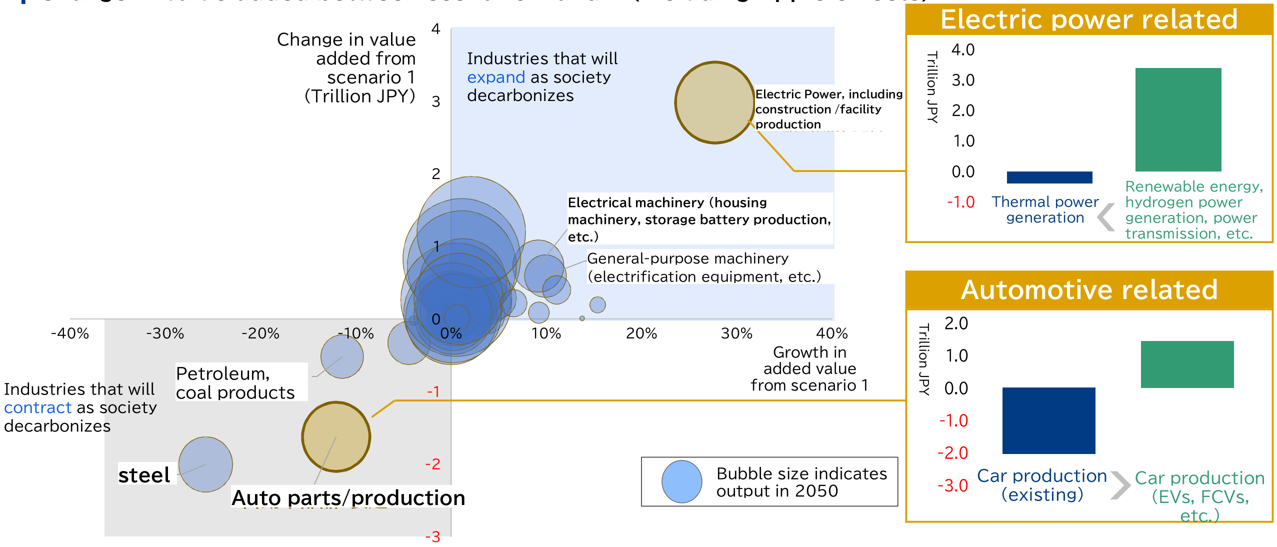
[8] Note the storage battery industry that is expected to grow because of EVs and FCVs is included in the industry classification as part of electrical machinery.

[9] However, we expect positive effects from the shift to EVs and FCVs mostly in service industries, including effects from uptake of car-sharing services etc.

Fig. 3-9: Some industries will expand while others contract as society decarbonizes

Change in value added between scenario 1 and 4 (including ripple effects)



Note: Comparison of scenario 4 with scenario 1, includes ripple effects
Source: MRI estimates, based on the Input-output table for analysis of next-generation energy system for 2015 from the Institute for Economic Analysis of Next-generation Science and Technology and Advanced Collaborative Research Organization for Smart Society (ACROSS) at Waseda University. Value added calculated as the total of direct effects + primary ripple effects + secondary ripple effects.

Employment gaps from the structural changes will be a major challenge

Employment will also be affected by the changes in industrial structure as society decarbonizes. We have analyzed the impact on employment numbers by applying (1) employment coefficients (number of people employed in each industry divided by the production value for the relevant industry; an indicator showing the amount of labor input per unit of production) for each industry in the economic ripple effects calculated for each scenario and (2) the activity level by each industry as set in our scenario analyses. We set employment coefficients for each industry that reflected variable factors by making reference to the input-output table (2015) from the Ministry of Internal Affairs and Communications; the incidental input-output table for analysis of next-generation energy systems for 2015[10] from the Institute for Economic Analysis of Next-generation Science and Technology at Waseda University; Matsumoto and Hondo[11] for solar power and wind power; and ERIA[12] for EVs and FCVs.

Figure 3-10 drills down into the results of these calculations to show the impact on employment versus the situation today for the electric power-related and automotive industries that will be significantly affected. For electricity businesses in the electric power-related industry, the shift from thermal power to renewable energy will result in a decrease in employment versus current levels, but there will also be a substantial increase in employment for construction and equipment production areas that build and produce equipment for wind power generation or electricity transmission. As a result, the electric power-related industry overall will see employment rise by approx. 100,000 people (+20%).

In contrast, in the automotive industry, there will be enormous negative impacts on employment, as changes in vehicle power sources combine with falling sales due to sharing services and the decreasing birth rate and aging population. The automotive industries included in this analysis can be broadly categorized as manufacturing, freight/passenger transportation, and sales/maintenance. Our analysis suggests significant decreases in employment in all three categories: manufacturing and materials −57%, freight/passenger transportation −39%, sales/maintenance etc. −40%. On top of this, the results show labor demand for automotive-related industries overall will fall from the current 5.5mn people to just over 3mn people

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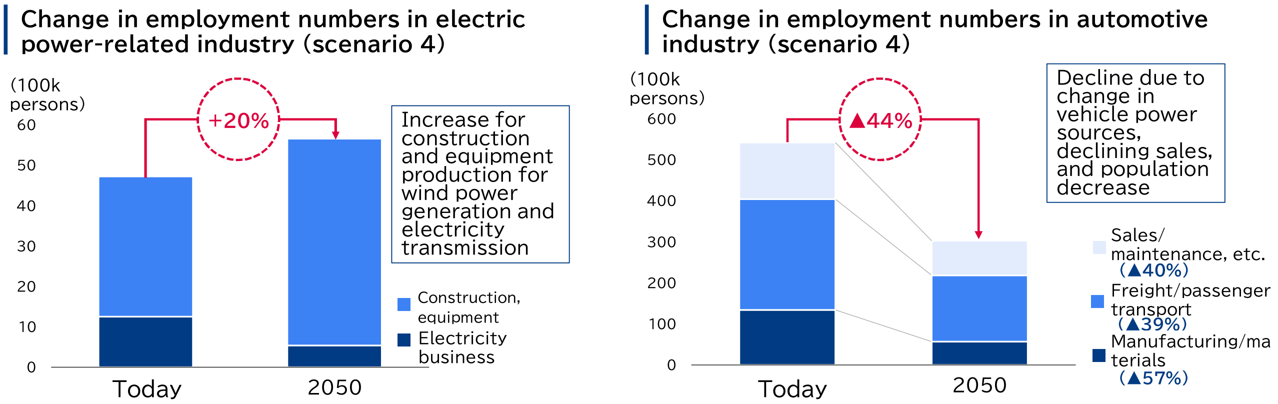
[10] Extended input-output table from the Institute for Economic Analysis of Next-generation Science and Technology at Waseda University https://www.f.waseda.jp/washizu/table.html

[11] Naoya Matsumoto, Hiroko Hondo, Analysis on Employment Effects of the Introduction of Renewable Energy Technologies Using an Extended Input-output Table, Journal of the Japan Institute of Energy 2011, 90 (3), 258-267

[12] ERIA (2020), Impacts on Industry by xEV Penetration, in Suehiro, S. and A.J. Purwanto (eds.), The Influence on Energy and the Economy of Electrified Vehicle Penetration in ASEAN. ERIA Research Project Report FY2020 no.14, Jakarta: ERIA, pp.28- 57

(−44%)[13]. As can be seen from these examples, the changes in industrial structure will require a significant shift in employment. Governments will face the enormous challenge of how to facilitate a seamless shift in human resources to growth industries in order to drive change in the industrial structure as society decarbonizes.

Fig. 3-10: Change in employment numbers in electric power-related and automotive industries (scenario 4)


Change in employment numbers in electric power-related industry (scenario 4)

Change in employment numbers in automotive industry (scenario 4)

Source: MRI estimates, based on the Input-output table for analysis of next-generation energy system for 2015 from the Institute for Economic Analysis of Next-generation Science and Technology and Advanced Collaborative Research Organization for Smart Society (ACROSS) at Waseda University

Note: Figures for today produced from Japan Automobile Manufacturers Association releases. Figures for 2050 (scenario 4) factor in decline in vehicle production and vehicle sales volumes due to uptake of sharing and decline in population. Assumes EVs account for 100% of short distance passenger vehicle sales in 2050, based on results from TIMES calculations.

Growing need for digital talent in carbon neutral fields as well

Our estimates of the change in employment structures as societies decarbonize do not include the impact from digital transformation (DX), but the large-scale introduction of renewable energy will need to use digitization to reduce costs and labor. For example, Figure 3-11 looks at the relationship between the introduction of solar power and job numbers, and shows that in developed countries, particularly Europe, there are low numbers of jobs per unit of solar power introduced. In contrast, Japan has not managed to reduce manpower in the same way, with job numbers some three times higher than in other developed nations. Actual interviews with industry bodies and business operators have highlighted the lack of digital talent and human resources capable of handling new technologies.

The Mitsubishi Research Institute's "Career shifts Toward Achieving DX and GX[14]" is of relevance to our research here. According to this report, DX (transformation into a digital society that involves companies, industries, and all society) and green transformation (GX; social transformation needed to decarbonize) are the two major tides of change sweeping through Japan's industrial structure, and the country needs to promote human resource mobility and invest in human capital if it is to achieve both DX and GX. The report highlights two career shifts that are particularly important to achieve this: "trying again," where people pursue training over the long term for specialized professional roles, and "developing creative human resources" aimed at training up the core human resources and the transformational human resources needed to achieve DX and GX. A precondition in the pursuit of decarbonization is that the public and the private sectors visualize what types of human resources are needed for this directional change in industrial structure and then work together to develop the human resources from a longer-term perspective.

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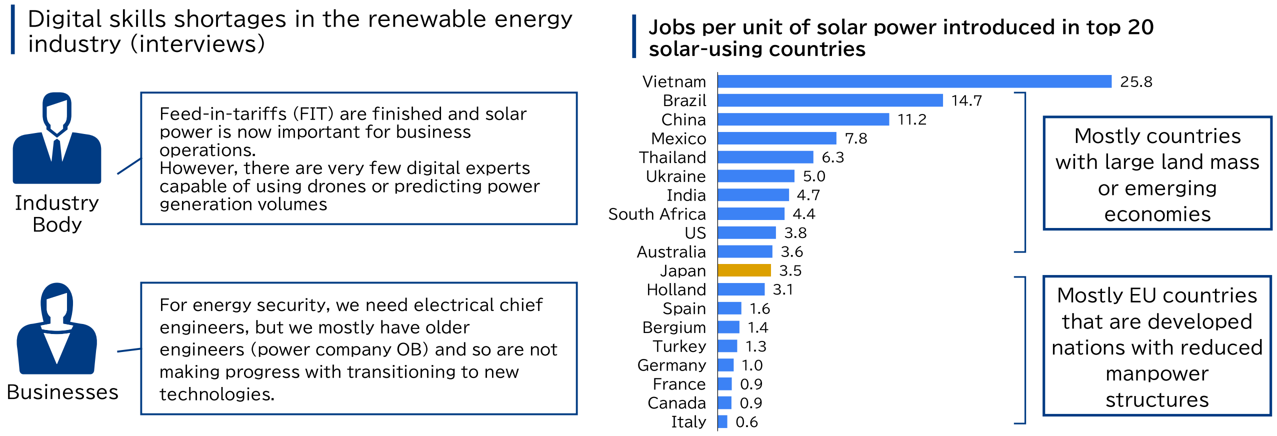
[13] As described in this report, the figures for the automotive industry not only reflect the impact from decarbonization ('green transformation' or GX), but also include the impact from sharing services and from sales volumes as the population declines.

[14] Masashi Santo, 2022, Career shifts as we achieve DX and GX, *MRI Monthly Review*, April 2022 issue, Special Feature 1, https://www.mri.co.jp/knowledge/mreview/202204.html

Fig. 3-11: Entrenched shortages in digital talent persist



Digital skills shortages in the renewable energy industry (interviews)

Industry Body: Feed-in-tariffs (FIT) are finished and solar power is now important for business operations. However, there are very few digital experts capable of using drones or predicting power generation volumes

Businesses: For energy security, we need electrical chief engineers, but we mostly have older engineers (power company OB) and so are not making progress with transitioning to new technologies.

Jobs per unit of solar power introduced in top 20 solar-using countries

Mostly countries with large land mass or emerging economies

Mostly EU countries that are developed nations with reduced manpower structures

Source: (Left) Interviews conducted by MRI. (Right) MRI, from data from the International Renewable Energy Agency (IRENA)

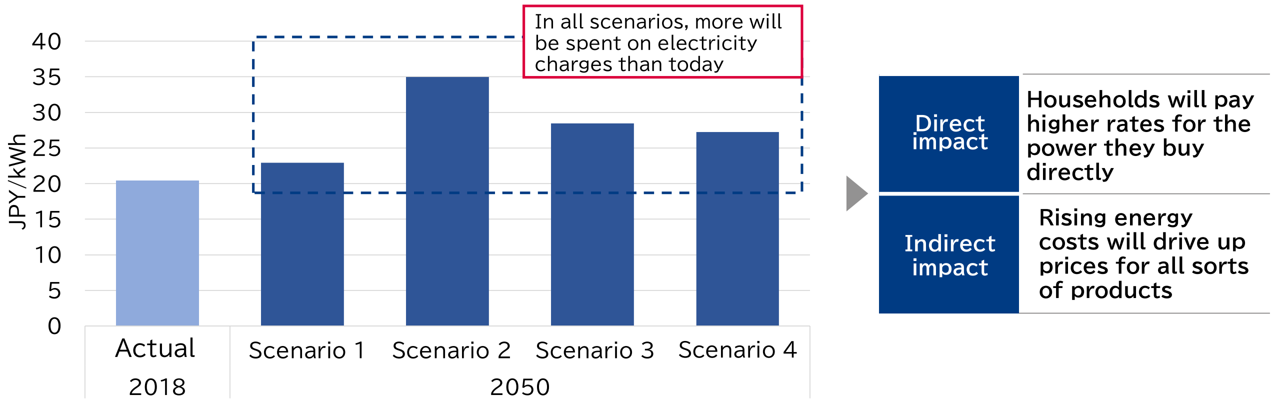
Expect higher burden on household finances, need to discuss how this pain is shared

As society decarbonizes, we expect variable costs (fuel costs) to decrease, including a decline in fossil fuel imports, but there will also be a significant rise in capital costs triggered by investment in new facilities, so we see a high probability of higher electricity charges than today in all scenarios. Looking at electricity rates for each scenario, we see that scenario 2 (mostly behavior change) has the highest rates, followed by scenario 3 (only technological innovation), then scenario 4 (two-pronged approach with behavior change and technological innovation), and finally scenario 1 (current trendline) (Figure 3-12). Higher electricity rates have a direct impact on households in terms of higher energy bills and also have an indirect impact on households because a rise in energy costs drives up the cost of living across the board. We need to manage this rise in the cost of living from higher energy prices in two ways, as follows.

First, we need to design charges so that they are fair and transparent. A change in electricity charges triggers higher prices for a wide range of goods and services and changes the entire price structure. The companies and households that make up the economy work to optimize themselves according to this price structure. To maximize the overall economic surplus and achieve efficient resource allocation, we need to design a system with fair and transparent charges that minimizes the strain on the market.

Second, we need to take into account regressive characteristics. Many essential goods would fall under the category of products where prices are expected to rise as electricity rates and energy costs rise, and this has regressive consequences. It is important for Japan to fully debate how the pain should be shared, taking into account other elements as well as energy prices.

Fig. 3-12: High probability that electricity charges will rise



In all scenarios, more will be spent on electricity charges than today

Direct impact: Households will pay higher rates for the power they buy directly

Indirect impact: Rising energy costs will drive up prices for all sorts of products

Source: Future values estimated by MRI. Actual values estimated using FY2018 power trading report and levies to promote renewable energy power generation. The values shown above are unit prices for the total of electric lighting and electric power, and do not include consumption tax.

4. Discussions we need to have *right now* as we move towards carbon neutrality

In chapters 2 and 3, we made a number of assumptions in our analysis of different scenarios for achieving carbon neutrality, but there are multiple challenges that need to be overcome if there is to be a smooth transition to a decarbonized society. In this chapter, we focus on three areas that we need to discuss *right now*: (1) how will we make behavior change happen, (2) what do we think about the positioning of nuclear power, and (3) how will we deal with "gray rhino" issues that we are aware of but are slow to act on?

4.1. Making behavior change happen

As already mentioned, in our recommendations on becoming carbon neutral by 2050 published in September 2021, we discussed the three key points of (1) changing demand-side behavior, (2) achieving net-zero emissions across the power sector at an early stage, and (3) fostering strategic innovation. We also pointed out that changing demand-side behavior needs to happen as early as possible.

Behavior is already starting to change to decarbonize, with companies participating in initiatives like RE100, SBT, and TCFD and consumers stepping up ethical purchasing. However, there is little motivation to get involved and little awareness of the emission reduction effects for some of the measures in place, and without proper measures in place behavior change will probably grind to a halt. To achieve a smooth transition to a decarbonized society, we need to identify the factors hampering behavior change and design appropriate measures to spur change.

People are motivated to engage with behavior change, and willing to pay, if big results are expected

In order to analyze demand-side motivation to engage with behavior change, hampering factors, and effective measures to promote behavior change, we defined specific behavior change examples (31 types for companies, 26 types for consumers) and then conducted a questionnaire-based survey in April 2022 with companies and consumers across Japan.

Figure 4-1 shows the motivation to engage, the recognized emissions reductions, and the amounts people are willing to pay for each behavior change item.

The results for both companies and consumers showed that the greater the emissions reductions expected, the more companies and consumers are motivated to engage with behavior change and the more they are willing to pay. However, there were some examples where companies and consumers expressed relatively little motivation to engage, even though they expected substantial emissions reductions and were willing to pay a certain amount. A case in point is on-site solar power generation. For this type of behavior change, we need to identify what are the factors hampering change and what type of measures would be most effective to promote behavior change.

We categorized behavior change into four types[15] and analyzed trends for each category. The results showed that it is particularly important to develop measures to promote a change in energy choices (e.g., switch to renewable energy, on-site energy generation), as this is an area where substantial emissions reductions are expected but there is low motivation to engage.

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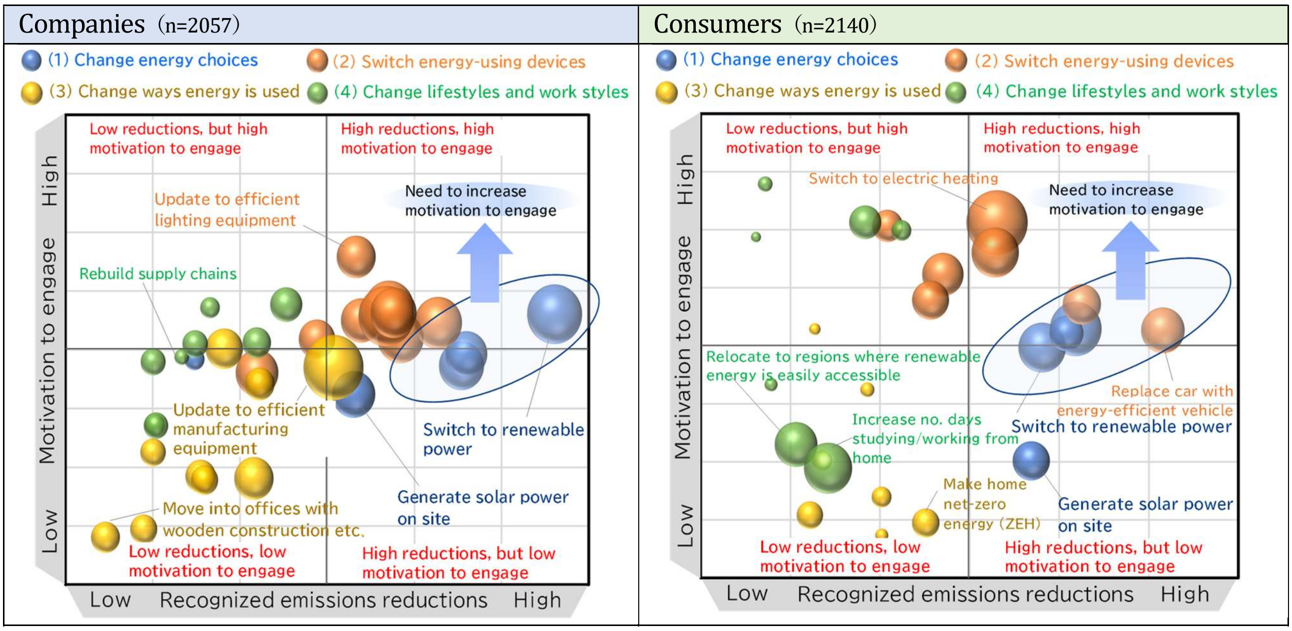
[15] In our recommendations on becoming carbon neutral by 2050, published by MRI in September 2021, we categorized demand-side behavior change into (1) change energy choices (e.g., switch to renewable energy, (2) switch energy-using devices (electrification, higher efficiency), (3) change ways energy is used (step up energy-saving behaviors), and (4) change lifestyles and work styles.

Fig. 4-1: Positive correlation seen between motivation to engage with behavior change, awareness of outcomes, and amounts willing to pay



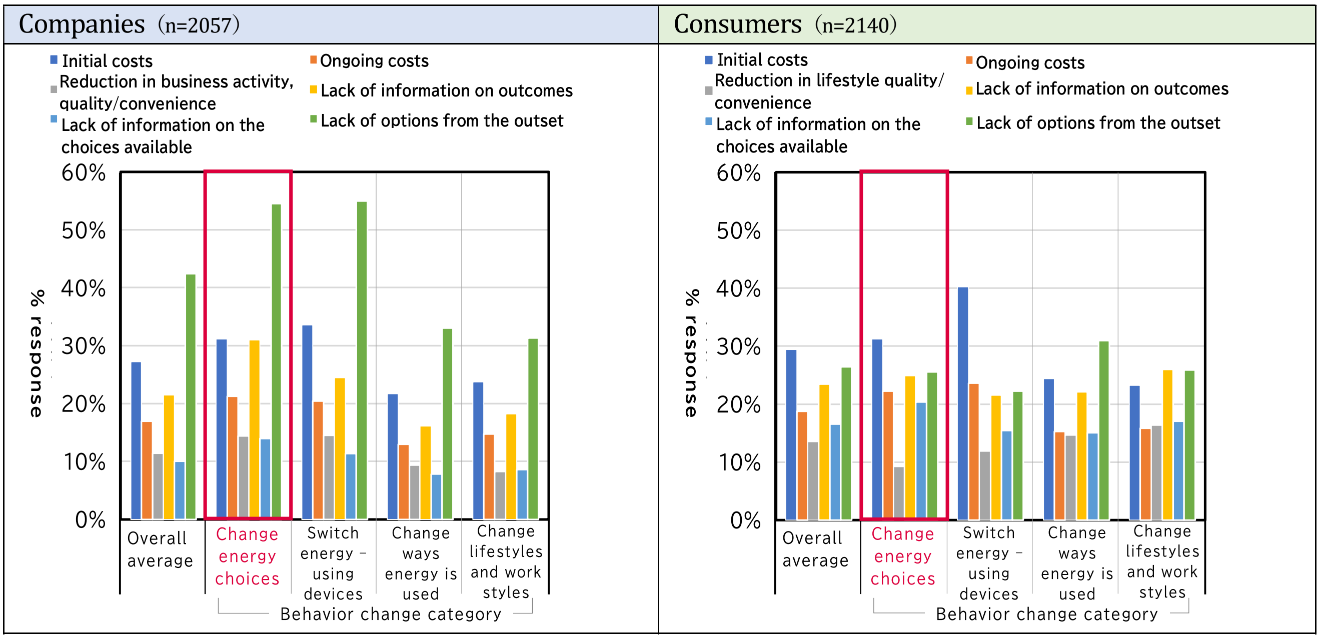
Source: MRI
Note: Size of bubble shows amount willing to pay

Main factors hampering change for both companies and consumers are lack of options from the outset, initial costs, and lack of information on outcomes

We then looked at the factors hampering engagement with the various types of behavior change, analyzing six factors: initial costs; ongoing costs; reduction in business activity/lifestyle quality or convenience; lack of information on outcomes; lack of information on the choices available; and lack of options from the outset (Figure 4-2).

For companies, the main factor hampering all types of behavior change was lack of options from the outset. In contrast, for consumers, the main factor hampering change differed according to the type of behavior change in question. For both companies and consumers, there were three relatively large factors hampering change: initial costs, lack of options from the outset, and lack of information on outcomes. These were the top three factors hampering change for both companies and consumers in the change in energy choices category discussed above, where substantial emissions reductions are expected but there is low motivation to engage.

Fig. 4-2: Main factors hampering change are lack of options, initial costs, and lack of information on outcomes



Source: MRI

Provide sufficient options and information is the most effective measure to change energy choices

We analyzed changes in motivation to engage (% increase) when the following measures to promote the various categories of behavior change were implemented: provide economic incentives; affect reputation with investors (for companies); confer a sense of fulfillment and accomplishment (for consumers); and provide sufficient options and information (Figure 4-3).

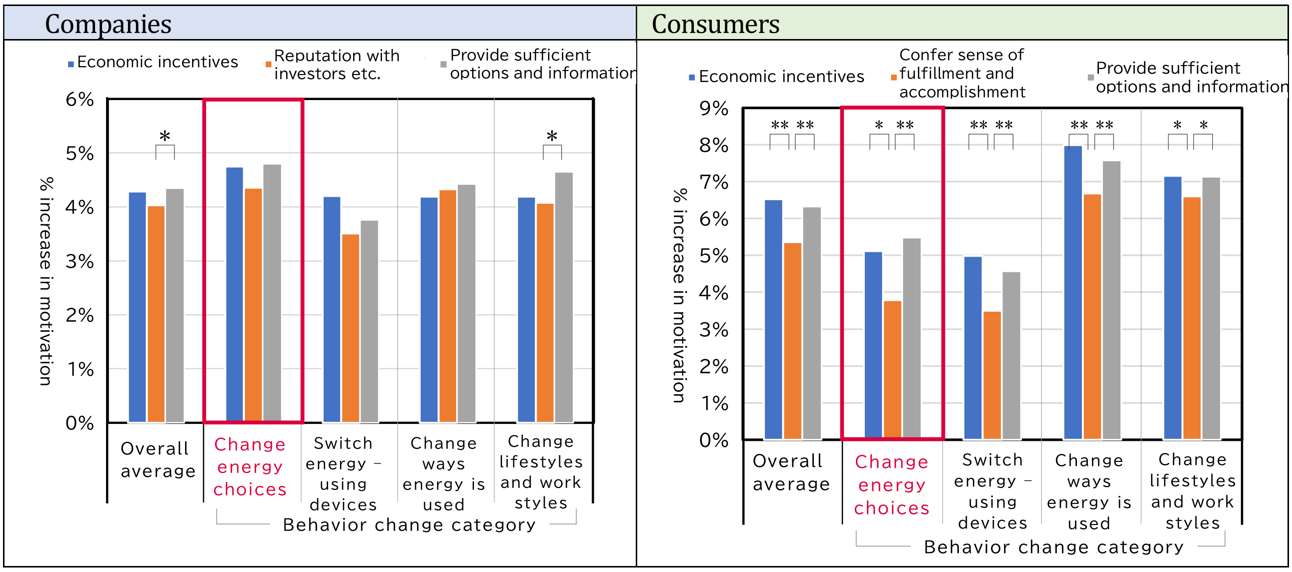
For companies, there were no statistically significant differences between the three methods and the results suggested that various methods can be effective, not just promotional measures involving economic incentives. For consumers, however, economic incentives and providing sufficient options and information were effective for all the types of behavior change.

For measures that involve comparisons with others or evaluations, such as affect reputation with investors (for companies) or confer a sense of fulfillment and accomplishment (for consumers), there were only limited results compared with other types of measures, but a comparison of the responses provided by companies and by consumers showed a tendency towards a comparatively stronger impact on the companies' motivation to engage. Promotional measures that make comparisons with other players or look at evaluations by other stakeholders may be effective with companies.

Focusing on the % increase in motivation to engage, we find providing sufficient options and information may produce the greatest increase in motivation to change energy choices by both companies and consumers alike. Because our research suggested that factors hampering behavior change are initial costs, lack of choices, and lack of information on outcomes, our analysis suggests a greater focus on programs that provide options and information on outcomes could be really effective in spurring behavior change. In particular, innovators and early adopters who lead the way in engaging with decarbonization can be expected to gather their own information and start making changes, but for the broader majority of the population, we need to provide carefully crafted information that is easy to understand. For example, when providing information on changing energy choices, providing a summary list of information on renewable energy power stations can help consumers choose the power supply that suits their own preferences. We think energy users may need this type of information to come from governments, organizations involved in various climate initiatives, and companies providing services to support energy choices.

The results of our questionnaire-based research suggest that we can expect companies and consumers to be spurred into action, depending on the type of measure implemented to promote behavior change. The most effective measures differ depending on the actual type of behavior change desired. To ensure that demand-side behavior change does not grind to a halt, we need to implement measures designed to be effective for particular types of behavior change and for all different kinds of demand-side players.

Fig. 4-3: Providing sufficient options and information produces the greatest increase in motivation to change energy choices



Source: MRI
Notes: * 5% threshold for significant difference ($p<0.05$), ** 1% threshold for significant difference ($p<0.01$)
The analysis excluded responses of "already done" and "will not engage even if I want to" for each of the specific items of behavior change. Therefore, the sample number may different from that for behavior change items (n = 1000–1500).

4.2. Positioning of nuclear power

Nuclear power generation is one factor that could have an enormous impact on the transition to carbon neutrality. Some eleven years have passed since the accident at Tokyo Electric Power Company (TEPCO) Fukushima Daiichi Nuclear Power Station. Today, ten nuclear power plants have already been restarted, but 26 plants are still not back in service (excluding those earmarked for decommissioning) and the future of nuclear power generation in Japan remains uncertain.

However, countries around the world are now facing a crisis in energy and economic security, with mounting concerns over worldwide LNG supply shortages and surging fossil fuel prices in the wake of the invasion of Ukraine in February 2022. Although various issues need to be addressed with nuclear power, including how to earn back the trust of society and how to dispose of radioactive waste material, the current climate has prompted governments to start looking at nuclear power once again. Nuclear power can provide stable electricity supplies and is carbon free, and it can potentially contribute to energy and economic security if positioned as semi-domestic energy production[16] and a high percentage of parts are procured domestically.[17]

Nuclear will co-exist with renewables even after their mass deployment

The aggressive use of nuclear power generation would increase stable carbon-zero energy supplies and could be useful as society becomes carbon neutral. We looked a little deeper into the concrete impacts nuclear power would have.

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[16] Nuclear power can be considered semi-domestic energy production with low external resource dependency: uranium, the fuel, is very energy dense and easy to store, can be reused after reprocessing, and accounts for a small percentage of total power generation costs.

[17] Agency of Natural Resources and Energy, Future Nuclear Power Policy, February 2022, https://www.meti.go.jp/shingikai/enecho/denryoku_gas/genshiryoku/pdf/024_03_00.pdf

To check the impacts described above, we conducted a sensitivity analysis based on four cases with different years in operational plant lives and different reactor numbers (Figure 4-4).[18], [19] We used the same assumptions in all four cases for factors other than nuclear power, including electricity demand and installed capacity for other power sources like solar, wind, and thermal. As in chapter 3, the use of our own MRI power source model allowed us to take into account the impact of interconnections between regions, matched supply and demand in 60-minute units by region, and power supply and demand balancing capability.

Figure 4-5 shows power generation mix and curtailment rates for renewable energy for each of the operating cases, as well as energy self-sufficiency. With more nuclear power plants in operation, thermal power plant operations can be scaled back such that thermal power generates a smaller percentage of total power. However, as more nuclear power plants are operated, the percentage of energy generated by renewable energy declines alongside that for thermal power and the curtailment rates for variable renewable energy (solar, wind) rise as well. We attribute this mostly to the assumption of a constant level of nuclear power plant in this investigation and the lack of a functioning power supply and demand balancing capability. From the perspective of energy security, as nuclear power plant operations are scaled up, the volume of fuel imports decrease and energy self-sufficiency improves.

As discussed above, renewable energy will need to be introduced in large quantities to achieve carbon neutrality, so it will be essential to secure power supply and demand balancing capability to ensure stable supplies. If more nuclear power were to be used, under the current constant output of nuclear power generation, there would be an increase in curtailment rates for variable renewable energy and a resulting decreasing in efficiency for the overall electric power system. Nuclear power will be an important option in terms of both decarbonization and energy/economic security. However, once renewable energy is in large-scale use, nuclear power will have to co-exist alongside renewable energy, which means nuclear power output will have to be adjusted through load following operations or energy conversion, such as to hydrogen production or for heat use.

Fig. 4-4: Four cases with different nuclear power operations

Case name	Summary	Installed capacity 2050
No operations	Zero nuclear power generation in 2050	0 GWe
Operating case 1	As for scenario 4 discussed in chapter 2	9 GWe
Operating case 2	Assumes all reactors[20] as of May 2022 (excluding those earmarked for decommissioning) will start operating and will have a 60-year service period	25 GWe
Operating case 3	Assumes all reactors as of May 2022 (excluding those earmarked for decommissioning) will start operating and will have an 80-year service period. Also assumes construction of a seventh new reactor (based on plans discussed in the past) to start operating in 2040 (installed capacity 10.2 GWe).	47 GWe

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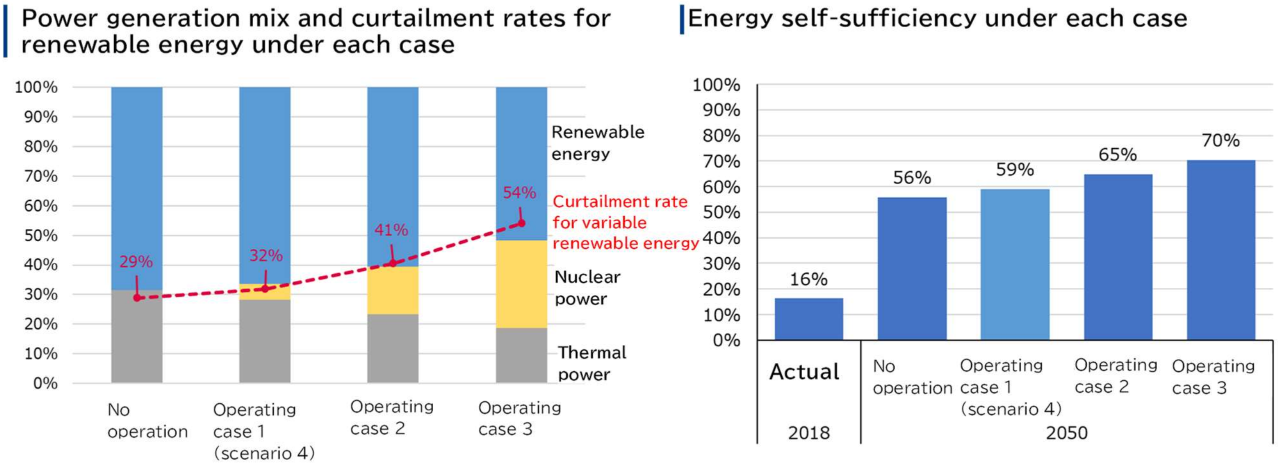
[18] After the accident at TEPCO's Fukushima Daiichi nuclear power station, Japan capped the operating period (service life) of nuclear plants at 40 years in principle but provided an "Operating Period Extension Approval System" that allows for a one-time 20-year extension if the granted by the Japan Nuclear Regulation Authority before expiration of the initial period. Approval has been granted for 60-year service periods at Takahama Units 1 and 2, Mihama Unit 3, and the Tokai Daini nuclear power station. In the US, as of April 2021, there are four reactors with approval for 80-year service periods and a further six reactors under review; this studytherefore allows for service periods extended to 80 years.

[19] Agency of Natural Resources and Energy, Maximizing the potential of nuclear power and pursuing safety, April 2021, https://www.meti.go.jp/shingikai/enecho/denryoku_gas/genshiryoku/pdf/023_03_00.pdf

[20] Agency of Natural Resources and Energy, Current status of nuclear power plants, as of 16 May 2022, https://www.enecho.meti.go.jp/category/electricity_and_gas/nuclear/001/pdf/001_02_001.pdf

Fig. 4-5: Introduction of nuclear power will improve energy self-sufficiency, but will also increase curtailment of renewable energy



Power generation mix and curtailment rates for renewable energy under each case

Energy self-sufficiency under each case

Source: MRI

Looking ahead to 2050: maintaining technology and human resources, plus nuclear power innovation

As discussed above, the invasion of Ukraine has worsened energy and economic security problems. To achieve Japan's GHG emissions target by 2030 (46% reduction versus 2013 levels), use of nuclear power plants meeting new safety standards looks more and more like a realistic option for the very near future.

That said, the current security risks will not simply go away when the Ukraine crisis is over. They could be ever present or worsen depending on the changing international situation. In addition, it is not the case that we simply need to be carbon neutral in 2050; we have to assume conditions that will continue after 2050. It is vital that energy policy takes a long-term view on decarbonization and security, and the message must be communicated that the nuclear power option should be left open in Japan.

Of all the various issues under discussion, we think that maintaining technology and human resources, plus innovation in nuclear power itself, are of particular importance. Technology and human resources are important not only to maintain infrastructure security, but also from an economic security perspective. It is urgent that Japan reconstitute its damaged nuclear power supply chain and accumulate a record of stable operations so as to keep the needed technology and human resource in Japan. For innovation in nuclear power, Japan needs to pursue this from a long-term perspective, investigating how to improve safety further and utilize nuclear power in a way that works with large-scale use of renewable energy as discussed before (e.g., load following, hydrogen production, and heat use).

As a prerequisite for the above, it is essential to genuinely address corporate governance and industry reforms to dispel the distrust of nuclear industry. Obviously, gaining social acceptance for nuclear power is a key issue. The Japanese government will need to engage in ongoing dialogue with society on how to decommission the TEPCO's Fukushima Daiichi Nuclear Power Station, operate existing nuclear power plants safely, and manage radioactive waste material.

4.3. Dealing with gray rhinos

Gray rhino was coined by US policy analyst Michele Wucker. It refers to a highly probable, high impact yet all too often neglected threat. Examples of gray rhinos include climate change, the debt crisis, and Japan's decreasing birthrate and aging population. Such problems gradually snowball over long periods of time and (seem) not urgent, so people are often slow to respond even though they understand the importance of the issue.

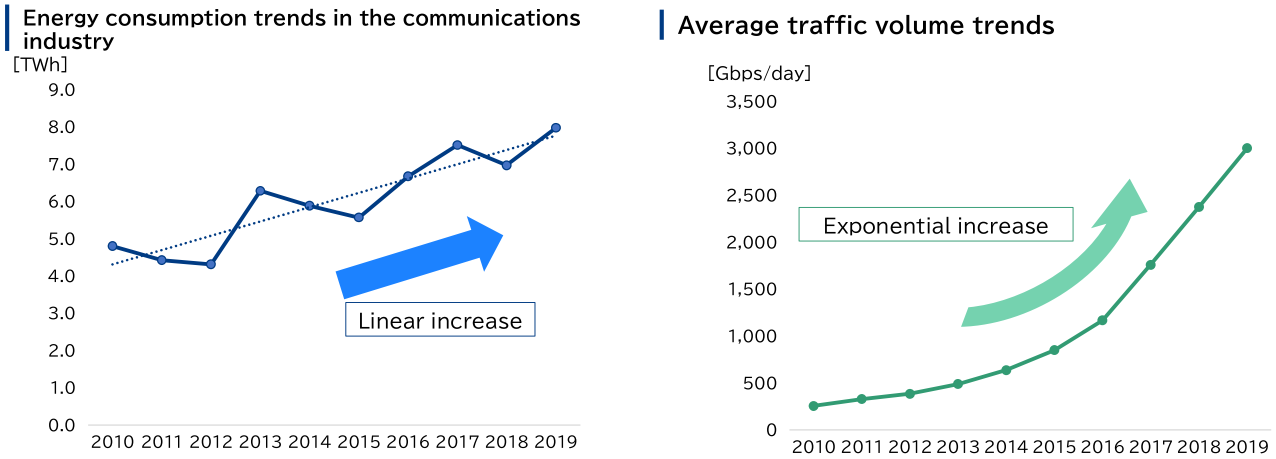
When a gray rhino fully materializes, it creates a huge crisis. When thinking about the move to carbon neutrality, we need to consider these often-postponed issues from the perspective of *right now*.

(1) Data explosion driven by digitalization

The first gray rhino we want to discuss here is the data explosion. As digital transformation of society proceeds apace, the volume of data processed and transmitted is predicted to increase exponentially. Looking at trends to date, the amount of electricity needed for data transmission will not increase as much as the increase in data traffic volume, but this is only because miniaturization and other technological advances have managed to reduce the electricity consumption rate (Figure 4-6).

However, we are not optimistic that this same trend will continue in the future. While various energy-saving network technologies are under development, such as NTT's Innovative Optical and Wireless Network (IWON) concept, the roll out across society of technologies such as self-driving cars and the metaverse will require the processing and transmission of huge volumes of data. It is unclear whether we can keep advancing technology over several decades to improve the electricity consumption rate enough to offset the exponential rise in data volumes. The data explosion has the potential to drive a significant increase in energy demand.

Fig. 4-6: Energy consumption for data transmission will not rise as much as traffic volume



Source: MRI, using electricity consumption in Total Energy Statistics for the communications industry[21] and Japan's internet traffic compilation and calculations from the Ministry of Internal Affairs and Communications

Excessive increase in electricity demand could hamper both carbon neutrality and digital transformation

If the data explosion does occur and we fail to improve electricity consumption rates enough to offset this, how will energy supply and demand structures be affected?

Figure 4-7 shows a simple visual of growth in electricity demand and the power generation mix if the data explosion does happen, assuming two cases described below the figure. A comparison of case 1 (same improvement in electricity consumption rates and a stable rise in data traffic) with case 2 (significant increase in traffic due to data explosion) shows that a roughly 15-fold rise in data traffic would drive up electricity demand for all Japan to nearly 200TWh.[22] This is roughly 20% of the current electricity demand for all Japan. To cover this increased electricity demand, we would need zero-emission thermal power as well as renewable energy, and the increase in power generation would be greater than renewable energy supply.[23] Total costs to satisfy energy supply and demand, from newly constructed facilities and higher hydrogen imports, would rise by some JPY 3 trillion and, from an energy and economic security perspective, would increase Japan's reliance on overseas players.

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[21] Total Energy Statistics for the communications industry are categorized into facilities for data communications processes using wired, wireless, and other electromagnetic methods and businesses providing such operations; includes data centers and network centers.

[22] There are factors other than traffic volume that will affect electricity demand for data transmission, but in these calculations to estimate the impacts, we assume the consumption rate (20% improvement per annum) is the electricity consumption per volume of data traffic. We assume annual traffic increase of 25% for case 1 and 37% for case 2.

[23] Government policy has a significant impact on nuclear power, so we have not made any changes to installed capacity. For the impact on nuclear power operations, see section 4.2.

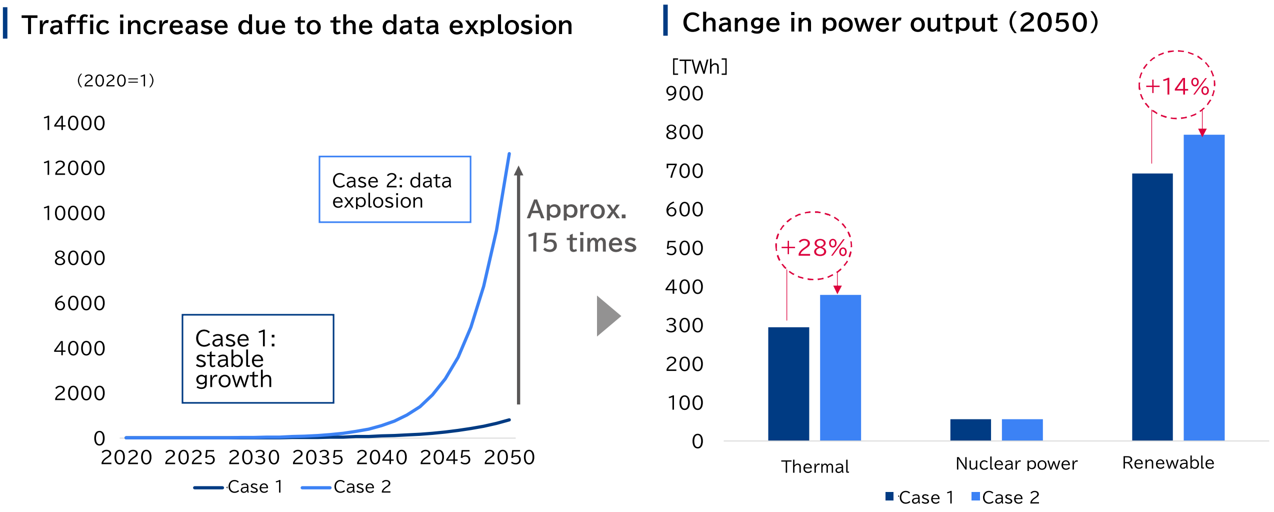
The above analysis assumes the improvement in consumption rate continues through 2050, but if technology development had come to a standstill there would be an even more explosive rise in electricity demand. Above a certain line, energy supplies would not be able to keep up. These constraints hampering energy supply and demand would slow growth by the IT industry and there might be negative impacts on other industries as well. Power supply constraints are a risk that could hamper DX and the transition to carbon neutrality.

Need distributed architecture combined with technological innovation

Digital transformation of society and the resulting increase in data volumes is unavoidable, so it is essential that we work continuously on energy-saving measures for all the data centers, networks, and end-user devices and on the technological innovation to support this.

In terms of system architecture, “distributed” is the keyword for both data transmission and energy. For data transmission, in the future there will be more usages requiring low latency, for example autonomous driving, and we anticipate an increase in local traffic including private networks and greater data utilization with the region. On the power side, this will mean increased electricity demand within the region, which could provide opportunities to reduce curtailment in those regions using a lot of renewable energy. Coexistence with local communities will be a major challenge for renewable energy uptake in the future, and it is important to take an integrated view on considerations of distributed architecture on the data transmission side and how regional energy supply and demand functions, including combinations with energy sources used regionally.

Fig. 4-7: Data explosion would require additional power generating facilities and fuel imports



Traffic increase due to the data explosion

Change in power output（2050）

Case 1: stable growth	Insufficient progress in technology development, data utilization infrastructure installment, and cost reductions, with limited uptake of innovative use cases, but growth rates maintained at around the same level as in the 4G and 5G eras
Case 2: data explosion	Widespread general uptake of innovative use cases through 2040, including autonomous driving and metaverse lifelogs, due to progress in technology development and resolution of the uncertainties over data use and application; this drives substantial data demand

Source: MRI

(2) More frequent and more severe natural disasters

Another example of a gray rhino is dealing with natural disasters. Japan only accounts for around 0.25% of global land area, but accounts for some 20% of the global cost of damage from natural disasters.[24] The most obvious example is the damage caused by the Great East Japan Earthquake in 2011, but in the 11 years since then, Japan has experienced around 30 earthquakes with a seismic intensity of 6 or above. The Fukushima Prefecture offshore earthquake on 16 March 2022 cut electricity supplies to as many as 2.2mn households across a wide area, including Tokyo. Estimates suggest that there is a roughly 70% probability of a Nankai megathrust earthquake or Tokyo near-field earthquake occurring by 2050, and there are also concerns over wind and storm damage becoming more frequent and more severe because of climate change. Japan needs to move towards carbon neutrality on the basis that a major natural disaster *will* rather than *might* occur.

Decarbonization of combustible energy sources is also important for ensuring resilience

With the move towards becoming a carbon-neutral society, we will have to (1) introduce renewable energy on a large scale and (2) pursue electrification and energy saving on the demand side. From a resilience perspective for both (1) and (2), it will also be important to decarbonize combustible energy sources such as hydrogen, ammonia, and synfuels.

For (1) large-scale use of renewable energy, one issue is how output varies over both short- and long-term time scales. A power shortage in eastern Japan on 22 March 2022 after an earthquake was caused by some power plants shutting down, and reduced interconnector capacity , combined with a sudden drop in temperatures that increased electricity demand. A substantial decline in solar power output at that time due to poor weather was another contributing factor. Japan needs to discuss how to maintain stable energy supplies as renewable energy systems, mostly solar and wind, are introduced on a large scale and there are even larger fluctuations in output as a result. As touched on in section 3.1, Japan will need zero-emission thermal power to compensate for variable output when renewable energy is being used on a large scale. Decarbonization of thermal plants is essential, therefore. However, as well as the short-term variations in solar and wind power described above that last from a few minutes to a few hours, we expect to see risk materialize from long-term variations in units of time spanning several months to years due to an ongoing worsening of wind patterns and water shortages impacting hydroelectric power generation.

Figure 4-8 shows trends in capacity utilization rates for solar, wind, and general hydroelectric power in 1-hour and 1-month units. Solar power is the most variable on a short-term scale, but is relatively stable on a long-term scale. General hydroelectric power is the opposite, due to the impact of seasonal variation or drought for example. To compensate for the risk from variable renewable energy output, Japan needs to build a portfolio that avoids overdependence on one type of power source and also ensures back-up power and energy sources. Japan must also be able to absorb relatively short-term variation (e.g., by using storage batteries), while also building up a certain level of energy reserves (e.g., hydrogen and synthetic fuels) to prepare for comparatively long-term output shortages.

Japan will also have to address (2) electrification and energy saving on the demand side as we build a decarbonized society, but there will be some consumers in very cold regions and industries for whom electrification of equipment will be an insurmountable challenge due to their manufacturing processes. Japan also needs to take into account localized power cuts that occur when there are major natural disasters (e.g., a Nankai megathrust earthquake or Tokyo near-field earthquake). As such, we should not ignore the potential use of combustible energy sources for end consumers, because this type of energy sources is easy to transport and store.

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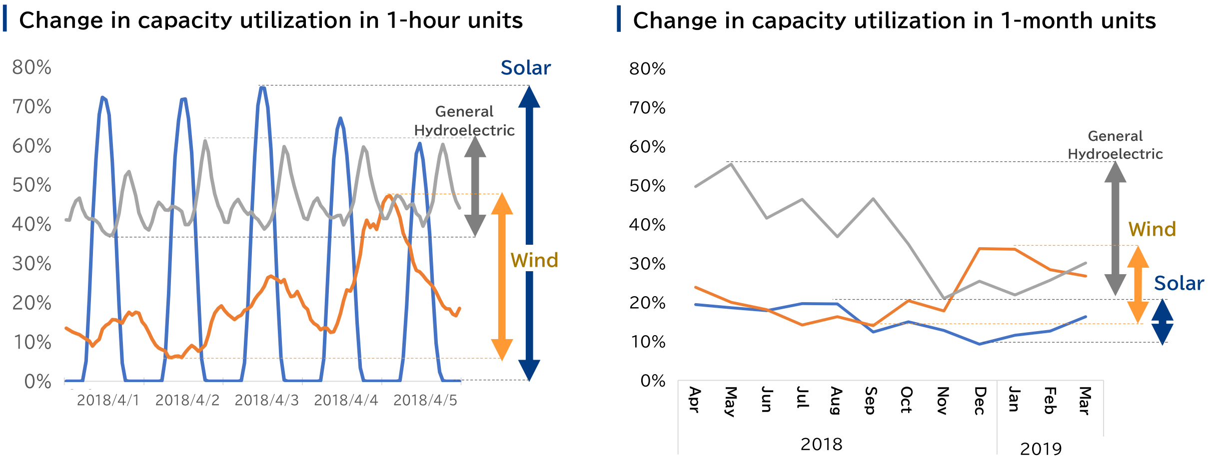
[24] Cabinet Office, White Paper on Disaster Preparedness (2020 and 2006 editions), https://www.bousai.go.jp/kaigirep/hakusho/index.html

Fig. 4-8: Time scale for variable output differs according to the type of renewable energy



Source: MRI, based on data from actual area supply/demand by general power transmission and distribution companies and power survey statistics from the Agency of Natural Resources and Energy

Need to be ready for anything on the demand side, both in normal times and during emergencies

Japan needs to have resilient systems in place to be ready for anything, both in normal times and during emergencies like major natural disasters.[25] The government partially amended the Electricity Business Act to establish a resilient and sustainable electricity supply system in June 2020, as part of its response to major natural disasters. The revised Act includes various measures to strengthen interconnections during emergencies, make the transmission network more resilient, and build a distributed power system capable of withstanding disasters. However, these measures are all aimed at the supply side. Japan will need to take a more integrated approach that includes the demand side, as Japan's power system is affected by the rise in prosumers and increasing awareness among demand-side consumers of safety and disaster preparedness.

It is important to be "ready for anything"; this means using something for a primary purpose during normal times, but also as a resource during emergencies.[26] For example, uptake of electric vehicles (EV) is an important component of Japan's pathway to carbon neutrality. The primary purpose of EVs is mobility, but they also have an important role to play as mobile storage batteries. EVs may be used as emergency power sources during emergencies or as a demand-side resource that contribute to stable system operations in normal times. On-site solar power generation, mostly by households, is valuable from an economic and environmental perspective, but could also give households self-sustaining capacity so they can utilize this energy during power outages.

Previously, business continuity planning (BCP) and other measures to improve demand-side resilience were considered a cost and were not seen as socially important or contributing to longer-term corporate value. There was also the view that disaster preparedness is hardly an attractive business. In the future, we need to evaluate the value of resilience properly and place greater importance on measures to drive behavior change among consumers so that they are "ready for anything" with self-sustaining and distributed capabilities. Japan will also need to take an integrated approach to disaster preparedness, not only covering individual consumers but also increasing resilience at the regional level and infrastructure beyond just energy systems.

Japan needs to double and redouble its efforts to ensure resilience, with simultaneous programs to decarbonize combustible energy sources that is easily transported and stored, strengthen energy supply systems, and improve consumer resilience.

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[25] The definition of energy resilience by the Agency of Natural Resources and Energy is based on the Asia-Pacific Economic Cooperation (APEC) Energy Resilience Principle, agreed in April 2020, that encompasses principles for stable energy supplies in normal times and emergencies.

[26] MRI, Achieving resilience by being ready for anything (published March 2022), https://www.mri.co.jp/knowledge/mreview/202203.html

5. Conclusion: Creating new industrial competitiveness from the social changes driven by decarbonization

In this report, we use scenario analyses to quantify the impact of the transition to carbon neutrality, not only for energy supply and demand but also in terms of the awareness of the challenges facing Japan as it transforms social structures. We also propose issues that need to be addressed and possible approaches to solving these issues on the road to a decarbonized society.

Carbon neutrality will have far-reaching consequences for Japan's society and economy that will spread beyond just energy-related industries. As we move toward carbon neutrality, rising demand for resources will bring new geopolitical risk and changing industrial structure will directly affect employment policy in terms of movement of human resources and reskilling. An excessive rise in energy demand due to the data explosion could also hamper both carbon neutrality and digital transformation. Japan also needs to consider its infrastructure as a whole, not just in terms of energy systems, when preparing for disasters. These issues are beyond the scope of traditional vertically organized industry and government bodies. Our analysis suggests Japan must implement programs with a transdisciplinary approach.

Japan faces numerous hurdles on the road to carbon neutrality: our industrial structure is dominated by manufacturing, much of our energy comes from thermal power generation, we have little by way of domestic zero-carbon energy supplies, there are few locations suitable for renewable energy, and we frequently experience major natural disasters. But other countries are tackling similar challenges head on. If we can overcome the obstacles discussed above, Japan may find itself on the road to new business opportunities and competitive capabilities, and also in a position to help other countries become carbon neutral.

While the world has experienced a number of "aftershocks" on the road to decarbonization, we assume that irreversible progress will be made over the medium and long term. Rather than being passive in the face of these waves of change, stakeholders in industry, government, and academia should work together to turn the social changes driven by decarbonization into a new competitive edge for Japan's industries.

6. Background material

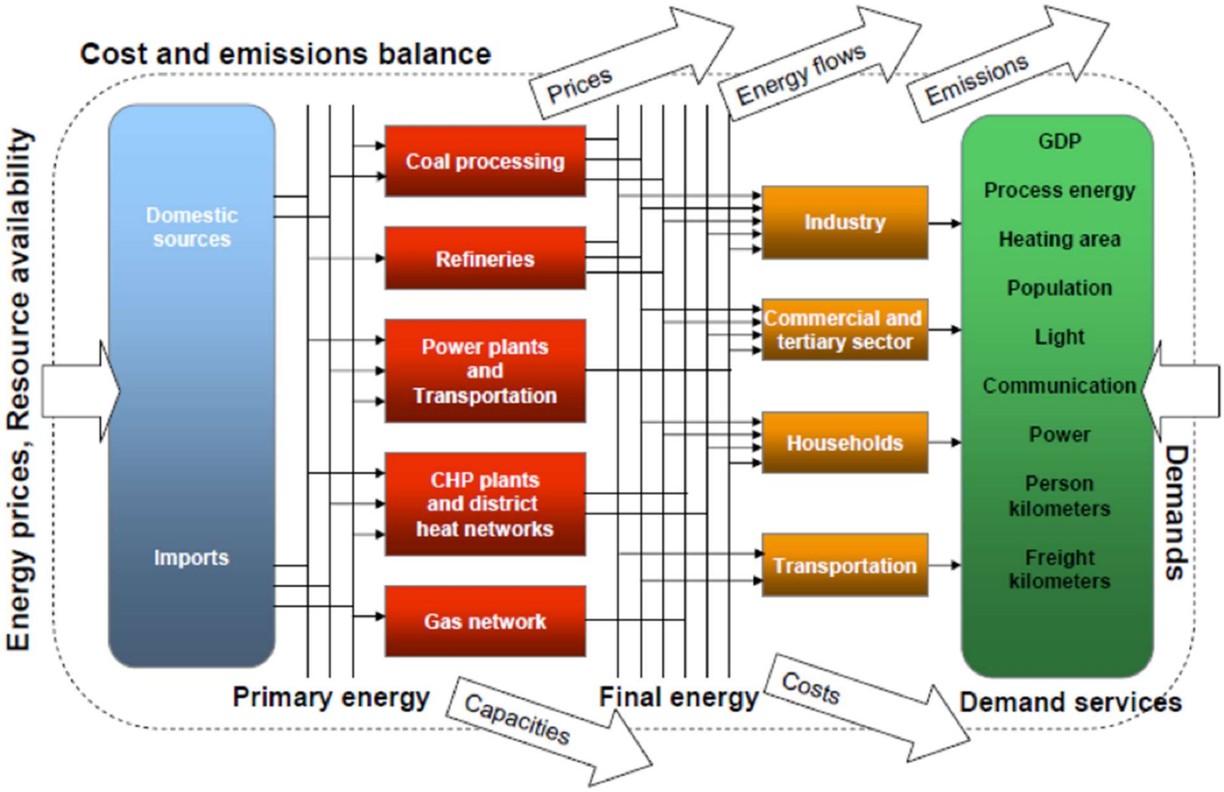
Overview of the TIMES model of energy supply/demand

The Integrated MARKAL-EFOM System (TIMES) model is a framework developed by the International Energy Agency (IEA) that is used by the IEA and numerous other research bodies around the world to model energy supply and demand. The model generator combines two systematic approaches to modeling energy: a technical engineering approach and an economic approach. The model generator uses linear-programming to produce a least-cost energy system, optimized according to a number of user constraints, over target time horizons.

One of the characteristics of the TIMES model is the ability to evaluate total energy supply and demand, not just for the electric power sector. The model encompasses all the steps in energy supply (primary resources through the chain of processes that transform and transport energy) and demand sides (industry, commercial/tertiary, households, transportation). Once all the inputs have been put in place, including resource and technology costs, supply constraints, and service demand, the TIMES model can be used to determine the optimized installed capacity and mix, energy costs, energy flows, and emissions.

The TIMES model is often used in scenario analysis tools. In this report, we prepared input data based on four future scenarios and analyzed what energy supply and demand would look like in a carbon-neutral society in 2050. For details on the input data used, see the next section Main preconditions for each scenario.

Overview of the TIMES model



Source: International Energy Agency (IEA) Energy Technology Systems Analysis Program

Main prerequisites for each scenario

In this report, we developed four scenarios for the future and analyzed the impacts on society from carbon neutrality in 2050. The main prerequisites for demand-side activity levels and supply-side technology in each scenario are as follows.

Under scenario 1 current trendline, we set the various factors by continuing current trends on both the demand and supply sides. For scenario 2 reduced demand, we factored into activity levels for each demand sector the impact of behaviors such as the sharing economy, circular economy, and digitization. For example, we set domestic auto production volume at around 3.2 million vehicles, crude steel production at around 58 million tons, and commercial floor space at around 1,440 million m^2. Under scenario 3 technological innovation, we expected impacts from innovation in the fields of renewable energy, hydrogen, steelmaking, and automobiles. For example, we set an upper limit of 416GW solar power generation introduced, imported hydrogen priced at JPY30/Nm^3, and H-DR steel and next-generation vehicles at levels capable of competing with existing technologies. For the two-pronged approach in scenario 4, we factored in the outcomes from both scenarios 2 and 3 at the same time.

Main parameters set for demand-side activity levels

World aiming for carbon neutrality

			Scenario 1: current trendline	Scenario 2: reduced demand	Scenario 3: technological innovation	Scenario 4: two-pronged approach
Activity level (in 2050)	Industry	Automotive Domestic production volume	Approx. 5.2 million vehicle	Approx. 3.2million vehicle Reduced demand from advances in the sharing economy, circular economy	Approx. 6.7million vehicle Increased exports due to innovation, domestic demand same as S1	Approx. 4.6million vehicle Same progress made as in S2 and S3
		Steel Crude steel output	Approx. 64 million ton	Approx. 58 million ton Lower demand for steel materials due to lower demand for cars and other end products, higher % use of electric furnaces	Approx. 77 million ton Lower demand for steel materials due to lower demand for cars and other end products, % use of electric furnaces same as S1	Approx. 72 million ton Same progress made as in S2 and S3
		Other	Change driven by same expectations as for automotive and steel			
	Buildings	Commercial Floor area	Approx. 1,800 million m2	Approx. 1,440 million m2 Reduced demand for offices (due to more remote working and active use of digital technologies) and for physical stores, hospitals etc.	Approx. 1,800 million m2 Same as S2	Approx. 1,440 million m2 Same as S2
		Households % households working from home	At home: not at home = 20:80	At home: not at home = 45:55 Higher % households working from home due to more people working remotely, actual number of households same as S1	At home: not at home = 20:80 Same as S1	At home: not at home = 45:55 Same as S2
		Device efficiency Mostly HP equipment	Efficiency improves through 2050	More efficient devices adopted 10 years sooner than S1 Upper limit on efficiency same as S1	Efficiency 1.1x better than S1 in 2050 Rate of adoption same as S1	Same progress as S2 and S3
	Transportation % change in passenger/freight demand (2020 = 100%)		Passenger: 100%, freight: 100%	Passenger: 70%, freight: 120% Passenger demand down but freight demand up due to active use of digital technologies	Passenger: 100%, freight: 100% Same as S1	Passenger: 70%, freight: 120% Same as S2

Source: MRI

Main parameters set for supply-side technology

World aiming for carbon neutrality

			Scenario 1: current trendline	Scenario 2: reduced demand	Scenario 3: technological innovation	Scenario 4: two-pronged approach
Power	Nuclear power		Same for all scenarios at 9GW (Only plants compliant with new standards are operating. No assumption of new builds or replacements.)			
	Solar	Upper limit	116GW (Home 17GW, business 99GW)	260GW (Home 53GW, business 207GW) *Based on reference values	416GW (Home 141GW, business 275GW) Assumes technological innovation, e.g., perovskite solar batteries, based on Ministry of Environment zoning research.	
		Cost	JPY170,000/kW (home JPY230,000/kW) *Cost Verification Working Group's assumptions for 2030		JPY100,000/kW *Cost Verification Working Group's cost reductions from 2020 to 2030 extended through to 2050	
	Wind	Upper limit	62GW (Onshore 40GW, offshore 22GW)	90GW (Onshore 45GW, offshore 45GW) *Based on reference values, public/private discussions	135GW (Onshore 45GW, offshore 90GW) *Onshore still based on reference values, offshore based on public/private discussions on industry targets	
		Cost	JPY250,000/kW *Cost Verification Working Group's assumptions for 2030 (offshore: ¥510,000/kW)		JPY150,000/kW *Cost Verification Working Group's cost reductions from 2020 to 2030 extended through to 2050 (offshore set at fixed costs equivalent to LCOE JPY10/kWh)	
Imported hydrogen			JPY100/Nm3 *Set at quite high cost levels		JPY30/Nm3 (S3), JPY20/Nm3 (S4) *With reference to government targets, S3 assumes tighter global supply/demand	
Hydrogen direct reduction (H-DR) steel			Assume zero *No technological innovation, current steelmaking methods still in use		Assumes costs at same level as current blast furnace steel *Based on values in paper from Lund University	
Next-generation automobiles			Costs in 2030 maintained for both EVs, FCVs (EV just under ¥3mn, FCV just under ¥4mn)		Costs reduced to same level as ICEV for both EVs, FCVs (Around ¥2mn)	

Source: MRI, from Advisory Committee for Natural Resources and Energy's Power Generation Cost Verification Working Group report

Overview of interindustry relations analysis

The interindustry relations analysis in this report broadly comprised three stages: creation of an extended input-output table, creation of a future input-output table, and analysis of economic and employment impacts. Below we provide a summary of the interindustry relations analysis.

Creation of an extended input-output table

To create the input-output table, we first investigated the industry categories needed and carefully examined the input vectors (input-output table columns) and output vectors (input-output table rows) for industries to be added to the base input-output table,[27] before working everything into a matrix. Below, we note the industry types added and the methods used to set the input and output vectors.

Industry types added and methods used to set input/output vectors in the extended input-output table

Industry type	Input vector	Output vector
(1) Hydrogen s(hydrogen production, imported hydrogen)	✓ Set same vectors as for coal mining, crude, petroleum, natural gas ✓ Electricity charges for hydrogen production set at 0 on assumption electricity will come from surplus renewable energy	✓ Set same vector as for natural gas
(2) Hydrogen production facilities (alkaline water electrolysis equipment)	✓ Stick with Waseda Uni method ✓ For costs, assign weighting by PCI[28] ratio	✓ Set same vector as for existing thermal power generation facilities
(3) Hydrogen reduction iron	✓ Set assuming shaft furnace (blast) + electric furnace ✓ Proportional distribution for production volume weighting, using pig iron + electric furnace ✓ Adjust materials—coal for hydrogen	✓ Set vector for pig iron + crude steel
(4) Hydrogen reduction iron equipment	✓ Set assuming shaft furnace (blast) + electric furnace (used consumption rate for electric furnace, shaft furnace based on overseas examples, and set total as vector)	✓ Set vector for pig iron + crude steel

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[27] Based on the Input-output table for analysis of next-generation energy system for 2015 from the Institute for Economic Analysis of Next-generation Science at Waseda University

[28] Japan Machinery Center for Trade and Investment's plant cost index (PCI), which publishes a rough breakdown of costs when a general chemical plant is being constructed

Industry type	Input vector	Output vector
(5) FCVs	✓ Stick with Waseda Uni method ✓ Replaced engine, gasoline tank for HVs (Waseda Uni 2005 edition) with stack, hydrogen tank for FCVs	✓ Set same vector as for passenger vehicles
(6) FCV trucks	✓ Set vector based on FCVs because of corresponding relationship between passenger vehicles and other vehicles	✓ Set same vector as for other vehicles
(7) Hydrogen power generation	✓ Set same vector as for existing thermal power generation ✓ Adjusted fuel component to reflect replacement of coal-fired power generation	✓ Set same vector as for existing thermal power generation
(8) Hydrogen power generation facilities	✓ From same method as Waseda Uni method (same as existing thermal power generation facilities)	✓ Set same vector as for existing thermal power generation facilities
(9) EVs	✓ Set vector from Waseda Uni 2011 edition (not disclosed in Waseda Uni 2015 edition)	✓ Set vector from Waseda Uni 2011 edition (not disclosed in Waseda Uni 2015 edition)
(10) EV trucks	✓ Set vector based on EVs because of corresponding relationship between passenger vehicles and other vehicles	✓ Set same vector as for other vehicles

Source: MRI

Creation of a future input-output table

When producing the extended input-output table, we added new industry types and set numerical values for each industry type under each scenario. However, this created inconsistencies in the input-output table columns (intermediate input, value added, output) and rows (intermediate demand, end demand, output) and was therefore inadequate as an input-output table for analysis. We therefore took the predicted data set in the extended input-output table, applied the RAS method[29] of predicting the input coefficient matrix as established by Stone et al. (1963)[30], and created a consistent input-output table (future input-output table) for each decarbonization scenario (four types: S1, S2, S3, and S4).

This method is based on the formula shown below. For the reference input coefficient matrix A0, we use the adjusted matrix R (diagonal matrix comprising coefficients showing change in intermediate demand) and the adjusted matrix S (diagonal matrix comprising coefficients showing change in intermediate inputs) to derive the input coefficient A’ at the forecast point from their matrix product, RAS.

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[29] The RAS method is also used to create Japan’s JIP database (RIETI) and IO for developing nations.

[30] Stone, R., J. Bates, and M. Bacharach (1963), Input-Output Relationships, 1954-1966, Chapman and Hall

During the calculations, we apply constraints to production output values (sum of rows, sum of columns), perform scaling on the matrix (matrix balancing) from both the row and the column perspectives until the constraints are met and perform convergent calculations, and derive the input coefficients. Please refer to papers by Takagawa and Okada (2004)[31] or Sano (2016)[32] for explanations and applications of the RAS method and examples of its use.

Analysis of economic and employment impacts

When performing an analysis of economic ripple effects, we derived an inverse matrix coefficient (a number that shows how many units of production value are induced at all sections by one unit of end-demand occurring at one section) for the future input-output tables created for each scenario. We then estimated the impact on output, value added and employment.[33]

(1) Economic ripple effects: output

To measure ripple effects on output, we used the value of end demand from the future input-output table for each scenario and the inverse matrix coefficient table. Specifically, to measure the economic ripple effects as we move from scenario 1 to scenario 4, we take the column vectors showing change in value of end demand in scenario 4 and scenario 1 and multiply them with the inverse matrix coefficient table to measure the value of output induced (induced output) (primary ripple effect). Then, some of the employee income arising from the primary ripple effect will increase consumption and this consumption demand will trigger more production. We used the input-output tables for each scenario to derive the rise in employee income from the increased output induced by the primary ripple effect and the amount by which demand increased in each industry brought about by the rise in employee income. We then created vectors for the change in the value of end demand and applied the inverse matrix coefficient table to measure the value of induced output as the secondary ripple effect.

(2) Economic ripple effects: value added

For value added, which equates to GDP, we measured value added coefficients (value added as a percentage of total output) for each industry from the future input-output tables for each scenario. We then applied this to (1) economic ripple effects: output to calculate the ripple effects on value added. Note that this is based on the output results, so we calculated both primary and secondary ripple effects for value added as well.

(3) Ripple effects on employment

The basic method used was to multiply the output calculated in (1) ripple effects by an employment coefficient (number of people employed in each industry divided by the production value for the relevant industry; an indicator showing the amount of labor input per unit of production) to calculate the ripple effects on employment.

When performing the calculations, for employment coefficients for conventional industries, we used the figures in the input-output tables (2015 edition) from the Ministry of Internal Affairs and Communications. However, for energy-related fields including renewable energy, we factored in change trends and change factors for each industry, making reference to the values in the incidental tables in the input-output table for analysis of next-generation energy system for 2015[34] from the Institute for Economic Analysis of Next-generation Science and Technology at Waseda University. We set employment coefficients with reference to

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[31] Izumi Takagawa, Toshihiro Okada (2004), Interdependent relationships between Asia-Pacific economies as shown by international input-output tables: analysis based on input coefficient predictions. Bank of Japan Working Paper Series, No. 04-J-6, March 2004

[32] Takao Sano (2016), Methods to estimate extensions of national input-output tables. In: Kanemori, Tamamura (eds.), Producing Asian international input-output tables—Challenges and extensions—Interim Report, Research Paper, Institute of Developing Economies, 2016

[33] Calculations of ripple effects using input-output tables start with demand (supply constraints are beyond scope of consideration). For this reason, it should be noted that a decline in automobile demand will lead to reduced manufacturing related to automotive production, but this method will not calculate how fewer automobiles will lead to reduced output by industries using vehicles. For example, if setting a decline in demand in industries using vehicles, the negative automobile output effects will be calculated as ripple effects.

[34] Extended input-output table from the Institute for Economic Analysis of Next-generation Science and Technology at Waseda University https://www.f.waseda.jp/washizu/table.html

Matsumoto and Hondo (2011)[35] for industry subcategories relating to solar and wind power that need particularly detailed scrutiny, and we referred to research by ERIA (2020)[36] for EVs and FCVs.

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[35] Naoya Matsumoto, Hiroko Hondo, Analysis on Employment Effects of the Introduction of Renewable Energy Technologies Using an Extended Input-output Table, Journal of the Japan Institute of Energy 2011, 90 (3), 258-267

[36] ERIA (2020), Impacts on Industry by xEV Penetration, in Suehiro, S. and A.J. Purwanto (eds.), The Influence on Energy and the Economy of Electrified Vehicle Penetration in ASEAN. ERIA Research Project Report FY2020 no.14, Jakarta: ERIA, pp.28- 57

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