May 30, 2023
Mitsubishi Research Institute

# Report on Transition to Carbon Neutrality

## Capital Flows, Resource Circulation, and International Collaboration Are Key

Tokyo (May 30, 2023)—Mitsubishi Research Institute (MRI) published a report on Japan's transition to carbon neutrality. Based on in-house scenario analysis, MRI has identified the key factors for smoothly shifting society to a decarbonized model while maintaining economic security and growth. With the country's 2050 carbon neutral targets set, MRI aims to guide the country toward its goals, first by shedding light on the steps needed to get there.

*The following is an overview of the report:*

### International community increasingly fractured, road to carbon neutrality increasingly uncertain

The Communique from the May 2023 G7 Summit in Hiroshima touched upon the latest report from the Intergovernmental Panel on Climate Change (IPCC). This report stated that human activities have already caused global warming to 1.1°C above pre-industrial revolution levels and this has led to widespread adverse impacts and related losses and damages. There is very little time left to combat climate change.

However, the transition to a decarbonized society is not progressing steadily. We have yet to achieve structural solutions to the energy market disruptions caused by the invasion of Ukraine. As well as the antagonism between the US and China, the Global South grouping of countries has started to assert themselves on the world stage in recent years and it is increasingly difficult to develop the international coordination and rules needed for decarbonization. From the perspective of decarbonization and economic security, the rebuilding of supply chains is also an important challenge for the private sector.

In the face of such mounting challenges, the road to decarbonization looks uncertain if based on idealistic or optimistic discussions alone. We need to define a vision for a realistic transition to carbon neutrality that does not damage economic security or economic growth.

### Basic transition scenario is two-pronged approach of behavior change and technological innovation

When analyzing scenarios for the transition to carbon neutrality, we can see that behavior change will play a key role through 2030, and technological innovation and roll-out across society will play key roles through 2050. When looked at from the perspective of end consumption, broadly speaking we see gradual progress in restructuring in the buildings, transport, and industry sectors. In the buildings sector, electrification and decarbonization of power generation will make significant contributions, while in the transport and industry sectors, these moves combined with measures in non-energy domains will boost contributions to reduced $CO_2$ emissions. Decarbonization of generation should not be skewed towards a particular source because of the technological characteristics of zero-emission energy sources (renewables, decarbonized thermal power, and nuclear power) and the different energy- and economic security-related risks.

Rising temperatures correlate with cumulative emissions, not emissions in a single year, so everything will not necessarily be fine if carbon neutrality is achieved just in 2050. Reducing cumulative emissions through early measures also means pursuing behavior change now and connecting this with subsequent technological innovation. Moreover, at the same time as this change in energy supply/demand structures, we need to also progress change in industrial structures. The automotive and energy-related industries will be impacted significantly, and we also need to encourage labor mobility at the right time to support this restructuring.

## Capital flows, resource circulation, and international collaboration are key to a smooth transition

To achieve a smooth transition, Japan needs to find a way forward with the following issues: How can Japan connect behavior change and technological innovation? As industry structures change, how can Japan ensure economic growth in a decarbonized society? And, as the global balance of power changes, how can Japan ensure energy and economic security? These questions are not easy to answer. We propose three factors that we think provide a key approach for Japan: (1) capital flows, (2) resource circulation, and (3) international collaboration.

### (1) Capital flows: Need appropriate carbon pricing to help connect behavior change with technological innovation

To achieve a smooth transition to a decarbonized society, Japan must promote capital flows into the necessary domains and achieve a shift to decarbonized industrial structures and economy. We expect carbon pricing to (1) promote demand-side behavior change by making the price of carbon visible and (2) support government revenues to provide the investment needed for R&D into decarbonized technologies and social roll out. We think carbon pricing has the potential to bridge the gap between behavior change and technological innovation.

For behavior change, the question currently being debated is whether carbon pricing can promote enough change in behavior. In questionnaire-based research with corporate and consumer respondents, only 15–40% of consumers and companies thought that behavior would be changed if the carbon price was set at the currently expected level of JPY2,000/t$CO_2$. Looking at the situation overseas, we can see that the carbon price needs to be set at the right level to drive behavior change.

For technological innovation, the public and private sector are expected to invest a total of JPY150 trillion over the next 10 years under the GX Promotion Act that came into force in May 2023, but our estimates suggest that investment to actually decarbonize will need to be stepped up after 2030, reaching a cumulative total of at least JPY320 trillion by 2050, particularly for renewable energy and next-generation automobiles. We look for proactive government involvement, as well as clarification on the medium- and long-term outlook for carbon pricing in order to improve private sector investment predictability.

### (2) Resource circulation: Need to secure decarbonized resources and also decarbonize materials fields

Resource circulation is an important approach for a country like Japan that lacks natural resources. The resources and manufactured products needed for decarbonization are being designated as strategic materials, and interest levels are running particularly high for metal resources. The metals that are included in critical minerals lists in Japan, the US, and Europe include some that are vital for decarbonization (used in renewable energy, storage batteries, and hydrogen manufacture). Such metals tend to be produced by only a handful of countries and are available on oligopolistic markets. Resource circulation has the potential to reduce the import volumes needed in the future and diminish risks to economic security.

Resource circulation can also be effective in reducing $CO_2$ emissions in hard-to-abate materials fields. For example, in the chemicals industry, it is expected that aggressive circulation of plastics could cut emissions by a further 20%. Japan needs to push ahead with resource circulation, working to appropriately quantify the emissions reductions achieved through individual initiatives, while also heeding the potential risks if this backfires (i.e., $CO_2$ emissions rise).

### (3) International collaboration: Key to new growth may lie in building energy systems that go beyond domestic boundaries and turning Japan into an investment-driven nation

International collaboration will be increasingly important for global decarbonization and future economic growth in Japan, and also from the perspective of economic security. Direct investment by Japan in ASEAN nations is rising each year and is currently running at twice the level of investment made by China, but ASEAN nations are also becoming increasingly reliant on the global superpower nations of the US and China.

Analysis of international trade models shows that if high carbon prices are introduced without the necessary structural changes in energy systems, industry competitiveness and economic security may be impacted in Japan and in ASEAN nations, for example due to a decline in trade balances and increasing reliance on specific countries for imports. From the perspective of economic security and economic growth therefore, it may become increasingly important for Japan to build complementary relationships with ASEAN nations just starting to decarbonize.

It is no easy matter to become carbon neutral and we hope Japan will look beyond its own domestic boundaries and take a broad perspective to the optimization of its energy systems, starting with collaboration with ASEAN nations. Using decarbonization as an opportunity, Japan should move away from its focus on trade and strengthen its position as an investment-driven nation. By leveraging the technological capabilities developed to date, we think Japan could build a new growth strategy through highly efficient and productive investments in other countries and industrial sectors.

**Full Report**

## Contents

# 1. Introduction: Ongoing turmoil on the road to carbon neutrality

The IPCC released the Sixth Assessment Report (AR6 Synthesis Report) on 20 March 2023. It is roughly eight and a half years since the release of the last Synthesis Report (AR5) in November 2014. AR6 highlighted that human activities have already caused global warming to 1.1°C above pre-industrial revolution levels, that vulnerable communities are disproportionately affected, and there is limited scope for continued $CO_2$ emissions if we are to limit the temperature rise to 1.5°C.[1] The situation is even more urgent and the world must take immediate, comprehensive action.

However, the transition to a decarbonized world is not progressing steadily. Global $CO_2$ emissions declined in 2020 when the pandemic brought economic activities to a halt, but emissions started to rise again in 2021 and are now at record high levels.[2] In 2022, Russia's invasion of Ukraine triggered huge turmoil on energy markets, impacting governments and economies around the world. With very little time left to combat climate change, the road to carbon neutrality looks increasingly uncertain.

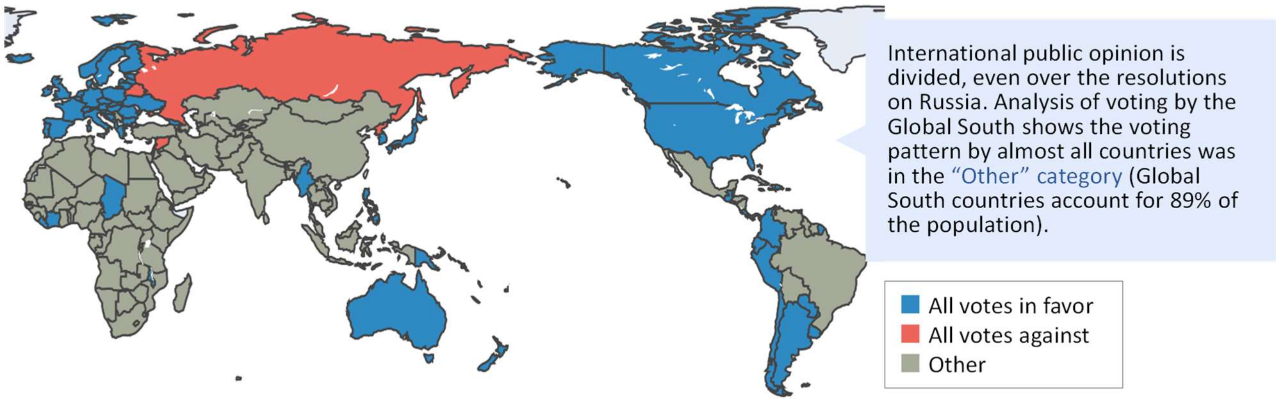
### Fracturing of the international community hampering measures to combat climate change

The international community is becoming increasingly fractured, including Russia's invasion of Ukraine and growing antagonism between the US and China, and the Global South[3] grouping of countries has recently started to assert themselves on the world stage independently of the three global superpowers. The Global South includes many countries that chose to abstain or not vote, rather than voting for or against, in the UN's resolution demanding Russia end its invasion of Ukraine and are starting to chart their own course (Figure 1-1). These countries have rapidly expanding economies due to population growth. The global power balance is becoming much more complicated than the old days of East versus West and it is increasingly difficult to develop the international coordination and rules needed for decarbonization.

The 27th Conference of the Parties (COP 27) of the UN Framework Convention on Climate Change (UNFCCC), held in Egypt in November 2022, is symbolic of these trends. At COP 26, discussions made progress towards decarbonization, including phased reductions in coal-fired thermal power and how to actually achieve the 1.5°C target, but the discussions at COP 27 were notable for the opposing positions of developed versus developing nations. One of the main factors behind this change is the impact rising energy prices have had on emerging economies. We think COP 27 served to remind us of how difficult it is to get all the parties involved to agree on and comply with measures to combat climate change.

**Fig. 1-1: More assertive Global South has complicated the global balance of power**

Voting in the UN resolutions on Russia (six rounds) between March 2022 and February 2023




Source: MRI, from UN materials

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1 IPCC, AR6 Synthesis Report, https://www.ipcc.ch/report/ar6/syr/ (accessed 11 April 2023)
2 Global Carbon Budget, https://www.globalcarbonproject.org/carbonbudget/ (accessed 11 April 2023)
3 Global South is often used as an alternative to terms like emerging nations, developing nations, or the Third World during the Cold War, but there is no clear definition. In this report, for convenience, we use this term to describe the Group of 77 (a coalition of 77 countries in Asia, Africa, and Central/South America that formed a group at the first UN Conference on Trade and Development meeting in 1964; currently expanded to 134 countries and regions).

## Countries moving to ensure energy and economic security

In light of this fracturing of the international community, countries are starting to take active steps to secure energy and economic security. In Europe, the European Commission unveiled the REPowerEU plan in March 2022 aimed at ending the region's dependence on Russian fossil fuels, followed by the Green Deal Industrial Plan in February 2023. These plans are both significant for economic security within the EU, as they include the Net-Zero Industry Act that aims to make the EU more competitive in decarbonized industries like solar and wind power, as well as the Critical Raw Materials Act that aims to ensure stable supplies of the critical materials needed for green and digital industries.

In the US as well, energy security is a major issue. The Biden administration enacted the Inflation Reduction Act (IRA) in August 2022, which will allocate $369 billion in funding—the highest ever budget—to energy security and climate change. The tax deductions on electric vehicles under the IRA come with tough content requirements; for example, vehicle the act mandates that vehicle components, particularly the batteries, must contain minimum percentages of inputs extracted, processed, or recycled in North America. The US is also promoting "friend-shoring" aimed at building supply chains in countries that are geopolitical allies.

Global supply chains have been built on economic rationale, but now need to change. However, it is not easy to rebuild supply chains and multiple practical issues will need to be overcome, including reconciliation of interests between the various countries and compromises on business activities. Given the constraints of stable energy supplies and economic security, it will be a major challenge for countries to work out how to achieve carbon neutrality or even whether this is possible at all.

## How Japan needs to transition to a decarbonized society

In Japan, the Cabinet agreed a Basic Policy on Green Transformation (GX) on February 10, 2023. The government's strategy is to realize public- and private-sector investments of over JPY150 trillion in GX over the next ten years. The Basic Policy proposes a number of measures, including the introduction of carbon pricing, and is expected to stimulate investment in various fields.

With the current jump in energy prices, however, companies and consumers alike are more cost conscious than before (see detailed discussion in chapter 3). Japanese companies are also having to deal with the real problem of supply chain risk following the invasion of Ukraine, but it is difficult to change suppliers while under pressure from high costs. In addition, there are still a number of gaps between government policy moves and the actual market situation on the ground. One example is that the main focus for new renewable energy thus far has been solar power generation, but the number of such facilities being installed and certified will cap out in a few years.

In the face of such mounting challenges, the road to decarbonization looks uncertain if based on idealistic or optimistic discussions alone. Japan needs to map out the transition to carbon neutrality in a way that takes into account both the current realities and the future outlook.

In our report Social and Economic Impacts of Carbon Neutrality in 2050,[4] published in November 2022, we set out four scenarios for Japan's future, discuss a vision for energy supply and demand in 2050, and calculate the impacts of carbon neutrality on society and the economy.

In this report, we expand on these themes further with a focus on the transition to carbon neutrality in 2050. We propose ideas for what needs to happen during transition and the key factors for how to realize these scenarios.

[4] https://www.mri.co.jp/en/news/20221104.html

# 2. Scenarios for the transition to carbon neutral

To show how Japan could achieve carbon neutrality, we set out four scenarios for Japan's future and investigated each scenario in our report Social and Economic Impacts of Carbon Neutrality in 2050, published in November 2022. In this chapter, we compare each of these scenarios in an analysis focused on changes in energy supply/demand structures and industry structures during the transition period.

## 2.1. Four future scenarios for the transition

The four scenarios discussed in this chapter were defined based on changing behavior on the demand side and technological innovation on the supply side (Figure 2-1). Behavior change on the demand side is where companies and consumers using energy (demand side) are motivated by their sense of values or economic/non-economic incentives to choose decarbonization, while technological innovation on the supply side refers to zero-carbon technologies being developed to the commercial level and rolled out across society.[5]

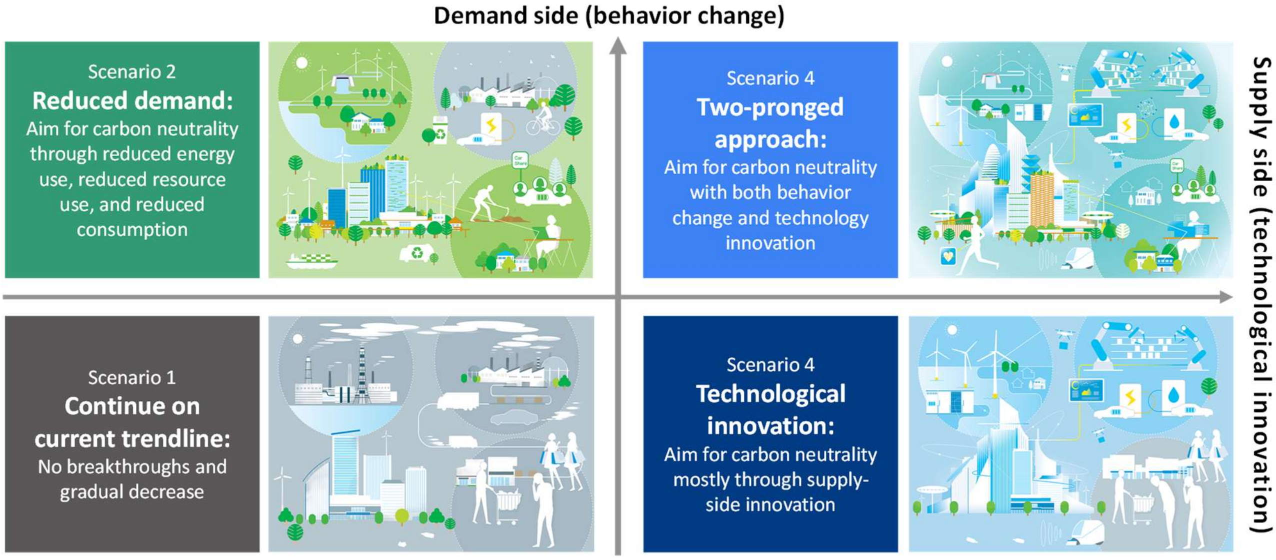
In scenario 1 "Continue on current trendline," there are no breakthroughs in behavior change or technological innovation and Japan continues along its current trajectory with a gradual decrease in emissions through 2050 and does not achieve carbon neutrality. Scenarios 2 and 3 feature either behavior change or technological innovation, but not both. In scenario 2 "Reduced demand," the goal is to achieve carbon neutrality through reduced energy use, reduced resource use, and reduced consumption, but no major technological innovation. In comparison, in scenario 3 "Technological innovation," 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 "Two-pronged approach," the world reaches carbon neutrality through both behavior change and technological innovation.

We use the same basic concepts as in our previous investigations, but in this report we set different carbon prices depending on the scenario and change the technology-related costs and levels introduced in the intervening years through to 2050. In addition, we make various changes, such as different thinking on the nuclear power policy, to reflect the Basic Policy on GX agreed by the Cabinet in February 2023.

Figure 2-2 shows the analytical framework used in this report. Based on global perspectives on the scenarios described above, we set parameters for the macro framework, activity level, and technology. We calculate energy demand structures using the Integrated MARKAL-EFOM System (TIMES) model of long-term energy supply and demand, as well as our PyDis, a python-based Security Constrained Economic Dispatch (SCED) model developed by MRI. These results were then used for interindustry relations analysis for 2030, 2040, and 2050 and quantification of the impacts on the economy and employment. See the Background material chapter for the detailed assumptions used.

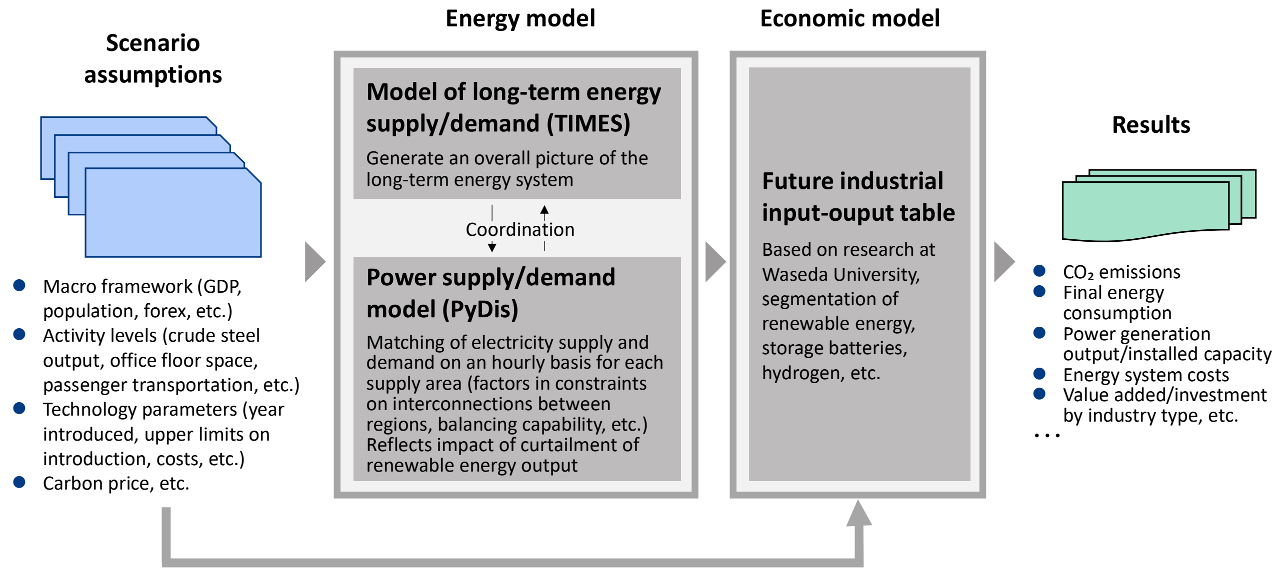
[5] Specific examples of behavior change include changing to renewable energy sources for electricity or changing from a gasoline-powered car to an electric vehicle. Specific examples of technological innovation include commercialization of next-generation photovoltaic batteries or storage batteries and lower costs for zero-carbon technologies.

**Fig. 2-1: Four scenarios based on demand-side behavior change and supply-side technological innovation**




Source: MRI

**Fig. 2-2: Quantifying a vision of the future by combining energy and economic models**




Source: MRI

## 2.2. Changes in energy supply/demand structures as Japan decarbonizes

### Basic transition scenario is two-pronged approach of behavior change and technological innovation

How will energy supply and demand structures change through 2050 under each scenario? In this chapter, we depict transition under each scenario, mostly based on the results from the energy models.

Figure 2-3 shows trends in greenhouse gas (GHG) emissions under each scenario.[6] Under scenario 1, the government does not implement a carbon price or emissions restrictions and GHG emissions decline in an organic fashion because of macro framework impacts from, for example, a decline in the population or stalled economic

[6] With this energy model, $CO_2$ emissions are calculated, after which exogenous negative emissions (e.g., other GHG emissions and forest absorption or CCS) are applied to arrive at the final calculation.

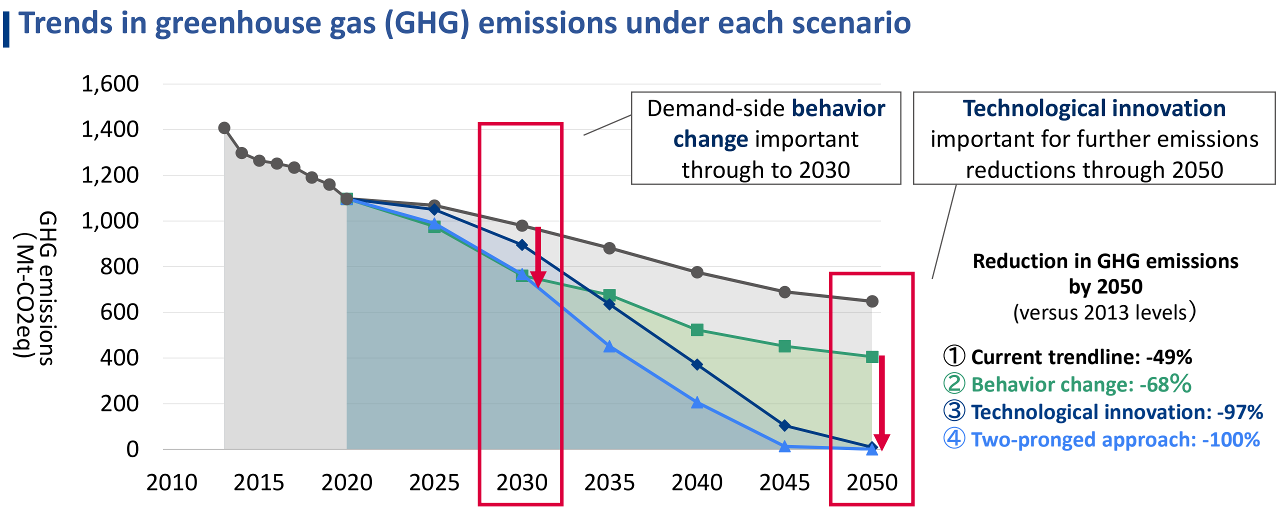
activity. Under scenarios 2, 3 and 4, the global goal of carbon neutrality leads to progress in emissions reductions, as carbon pricing functions effectively through government/local government regulations and voluntary efforts by companies and consumers, plus implementation of corresponding measures. In scenario 3, we apply a carbon price at the level used by the International Energy Agency (IEA) in the Net Zero scenario for developed nations. In scenarios 2 and 4, we assume a world where corporate and consumer behavior changes and the same carbon price is introduced ten years earlier, which results in emissions reductions at an earlier stage than in scenario 3.

Looking at the profiles in 2030, under scenarios 2 and 4 where behavior changes and a carbon price is functioning from at an early stage, emissions get close to the government target of a 46% decline versus 2013 levels. In contrast, in scenario 3, technological innovation comes too late resulting in insufficient emissions reductions. Comparatively speaking, as we move through to 2050, there are limitations to what behavior change alone can accomplish, as seen in scenario 2, so it is apparent that the roll out of technological innovation across society as assumed in scenarios 3 and 4 is essential if Japan is to become carbon neutral.

Let's think through the significance of this behavior change once again. Carbon neutrality is almost reached by 2050 under scenario 3, but that does not mean that behavior does not need to change. This is partly due to cumulative emissions. Rising temperatures correlate with cumulative emissions, not emissions in a single year, so everything will not necessarily be fine if carbon neutrality is achieved just in the year 2050. The difference in cumulative emissions by 2050 between scenarios 3 and 4 currently equates to around three years' worth of emissions (3.2Gt-$CO_2$). It is important to implement measures early to bring down cumulative emissions. Furthermore, it is expected that actual behavior change will give a boost to technological innovation. For the market for zero-carbon technologies to expand, we need companies and consumers to discover the value of these technologies or to be forced to start using them.

There is no point in developing new technologies if they do not get rolled out across society. For a smooth transition to carbon neutrality, Japan needs to work out how to organically tie in behavior change by energy users on the demand side with technological innovation to decarbonize over the medium-to-long term.

**Fig. 2-3: Two-pronged approach combining behavior change and technological innovation needed for a smooth transition**




* Value considers negative emissions, e.g., CCS and land use
Source: MRI

## Patterns of energy consumption will change in the buildings sector first, followed by the transport and industry sectors

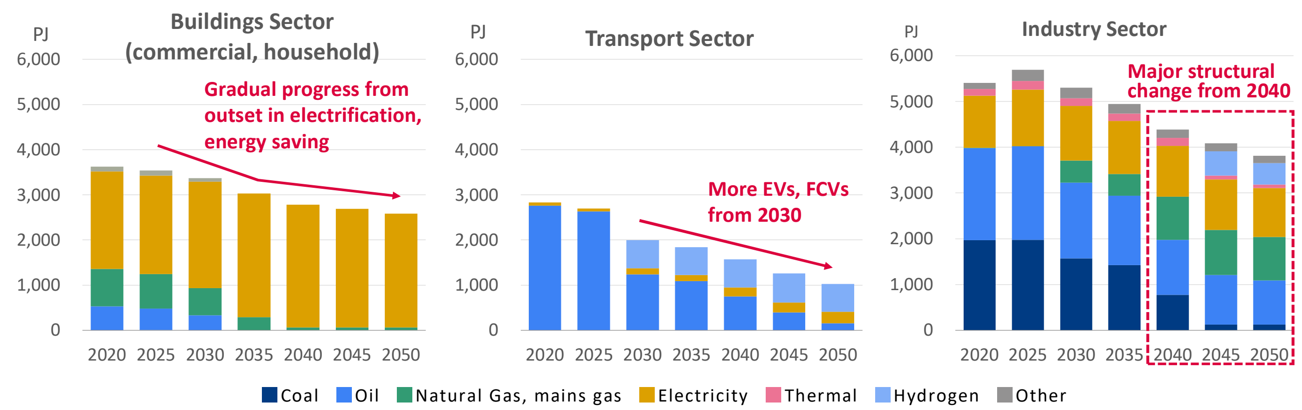
Here we focus on the change in energy supply and demand structures under the two-pronged approach of behavior change and technological innovation assumed in scenario 4. Figure 2-4 shows trends in final energy consumption in each of these sectors.

In the buildings sector (commercial and household), electricity currently accounts for a high percentage of final energy consumption and this percentage will gradually increase as progress is made with electrification and energy efficiency. Next, in the transport sector, there will be full-scale introduction of electric vehicles (EVs) for passenger cars and fuel-cell vehicles (FCV) for trucks from 2030. Energy consumption by EVs appears low because they are highly efficient in terms of energy usage per distance travelled, but there are many more EVs than FCVs on the world's roads. In the industry sector, as industries decarbonize, overall energy consumption declines (greater energy efficiency) and fuels are switched from carbon to natural gas. Fossil fuels will still be part of the equation to some degree because they will still be used in the chemicals and some other industries. We expect real changes in the pattern of energy consumption in the industry sector to get under way from 2040.

Over time, we can see that the buildings sector, where most demand-side measures are focused, will change immediately, while the transport and industry sectors that require technological innovation will only undergo substantial structural changes starting in the 2030s and 2040s, respectively.

**Fig. 2-4: Timing of structural changes in energy consumption differ by sector**

**Changes in final energy consumption under scenario 4 (two-pronged approach)**




Source: MRI

## Significant differences between the sectors in what actually contributes to reduced emissions

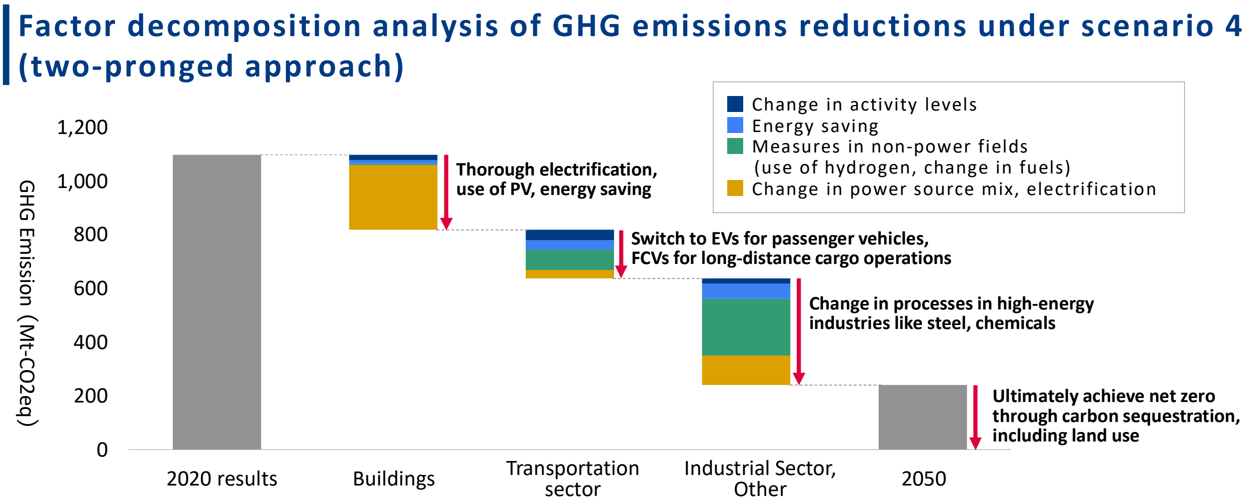
Now, let's discuss the degree to which the structural changes outlined above will contribute to reduced $CO_2$ emissions. We performed a factor decomposition analysis based on the Kaya identity approach[7] in order to analyze how much each measure contributes to emissions reductions. In this analysis, we break down the various elements, such as amount of $CO_2$ emissions, energy consumption/mix, and amount of activity, and map the changes over time in each sector.

Figure 2-5 shows the results from this analysis. In the buildings sector, there are significant contributions from electrification and changes in energy supply mix, and the two-pronged approach to measures in the power generation sector plays an important role, while in the transport sector, vehicle electrification (shift to EVs, FCVs) is extremely important. In the industry sector, $CO_2$ emissions are reduced significantly, including substantial contributions from measures in non-energy fields. This suggests there is significant potential for emissions reductions in hard-to-abate fields, such as in hydrogen direct reduction (H-DR) steelmaking or conversion of fuels and processes in the chemicals industry.

As discussed above, there are differences between different sectors in terms of the particular mix of energy consumption or the timing of the social implementation of anticipated zero-carbon technologies. For a smooth transition to happen, Japan needs to account for the particular characteristics on the demand side and also understand the expected impacts from the various technologies.

[7] Method of factor decomposition analysis developed by Yoichi Kaya (Emeritus Professor at the University of Tokyo). This method is referred to by the IPCC and used for decomposition analysis in various published papers.

**Fig. 2-5: Factors contributing to reduced $CO_2$ emissions differing between sectors**




Source: MRI

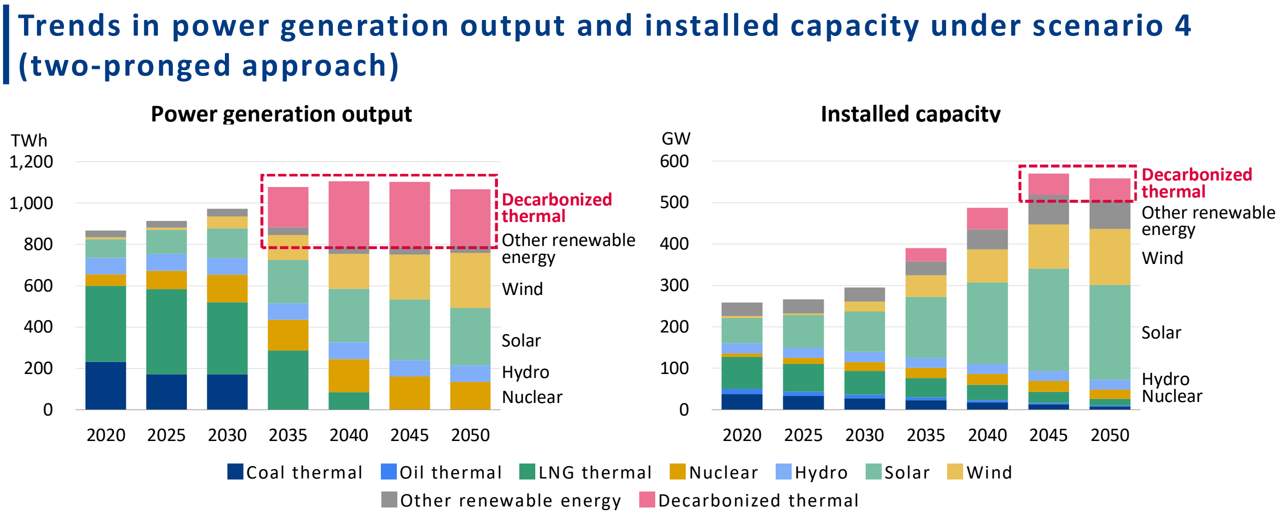
## Need the best mix from among zero-carbon energy sources

Figure 2-6 shows power output and installed capacity in the power generation sector. In this analysis, we use our own security constraint economic dispatch (SCED) model, called PyDis. We divide Japan into ten regions, factor in constraints on interconnections between regions and load frequency control (LFC), and simulate supply and demand matching in 60-minute units by region.

For conventional thermal power, installed capacity is significantly reduced and power output falls sharply from 2030, but decarbonized thermal power (e.g., using hydrogen or ammonia fuels) is increasingly important to retain the necessary balancing capability. For renewable energy, we see the introduction of mostly variable renewable energy (VRE) (solar, wind), but output is increasingly subject to curtailment as more VRE is introduced, so output does not increase in line with installed capacity. For nuclear power, we take into account the changes from the Basic Policy on GX and assume 22GW operations as of 2050, accounting for 10–20% of power output.

As discussed above, decarbonization of the power generation sector is essential as demand-side electrification progresses, mainly in the buildings sector. However, Japan should not favor a particular -energy source or sources. Zero-emissions sources—renewables, decarbonized thermal, and nuclear—each come with their own technological advantages and disadvantages and present different risks to energy and economic security. For example, compared with other power sources, solar power requires a lot of copper and aluminum and wind power requires a lot of copper and rare earth metals, while the storage batteries needed to support VRE use a lot of cobalt and nickel. The hydrolysis needed for hydrogen production requires platinum group metal catalysts. As well as all these metal resources, there are complex supply chains involved in the production of equipment and materials needed to decarbonize, and each supply chain is associated with different geopolitical risk. Given the uncertainties of technological innovation, we think Japan should not overly favor any single energy source, but instead needs to explore the best mix of all the zero-carbon energy sources.

**Fig. 2-6: Increasing need for decarbonized thermal power as current thermal power phased out**




Excludes power generation at small-scale power sources, such as in-house thermal power
Source: MRI

## 2.3. Changes in industry structures as Japan decarbonizes

### Mix of value added within industries will change as Japan decarbonizes

The transition to carbon neutrality will not only change the structure of energy supply and demand, it will also bring about changes in the various associated industry structures. In our report Social and Economic Impacts of Carbon Neutrality in 2050, published in November 2022, we analyzed the changes in output and value added in 2050 as Japan decarbonizes and demonstrated which industries will expand and which will contract. In this latest report, we focus on the process of transition.

We use the same analytical methods as in our 2022 report, namely future input-output tables created for each scenario and analysis of the economic ripple effects based on the results from our long-term energy supply/demand model (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),[8] before calculating the amount of investment needed by each industry. Note that our analysis assumes economic ripple effects through to secondary ripple effects.

Figure 2-7 shows the results from scenario 4 where the most progress is made in decarbonization. We can see trends in value added for the automotive manufacturing and power industries where there will be the most obvious changes in industrial structures. In the automotive manufacturing sector, including the auto parts industry, the mix of value added will change as electric-powered vehicles (EVs, FCVs) are taken up, such that by around 2040 there is a reversal in the value added of internal combustion engine (ICE) vehicles versus next-generation vehicles. In power-related industries, including power facility construction and parts manufacturing, we see an increase in value added for on the facility construction side, rather than for power generation businesses including for renewable energies. We attribute this to two factors: (1) for solar and wind power, the two main types of renewable energy being installed, there are no fuel costs, so capital costs make up most of the cost mix, and (2) for the construction of wind power generation facilities in particular, there are very long supply chains for everything from planning and design through to maintenance, so substantial value added is created once we extend the analysis through to secondary ripple effects. Our analysis suggests that even within the same industry, there is a shift over time in the business types accounting for most of the value added.

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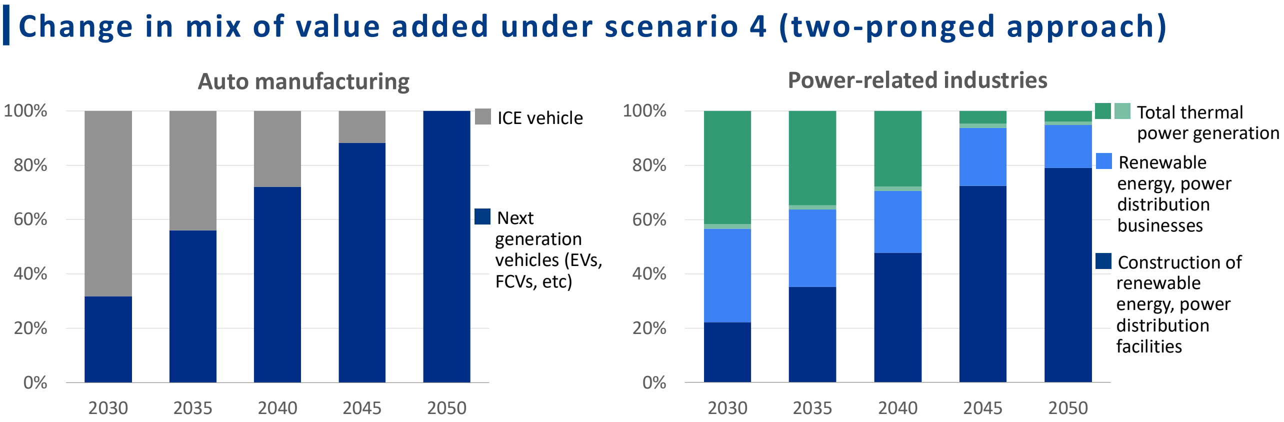
[8] For an overview of interindustry relations analysis and the methods used to create a future industry input-output table and its use in the analysis of economic and employment impacts, see the background material on “Overview of interindustry relations analysis” in our report Social and Economic Impacts of Carbon Neutrality in 2050
https://www.mri.co.jp/en/news/dia6ou000004s1st-att/nr20221104.pdf

**Fig. 2-7: Mix of value added will shift even within the same industry**




Source: MRI

### Higher labor mobility needs to come at the right time to promote industry restructuring

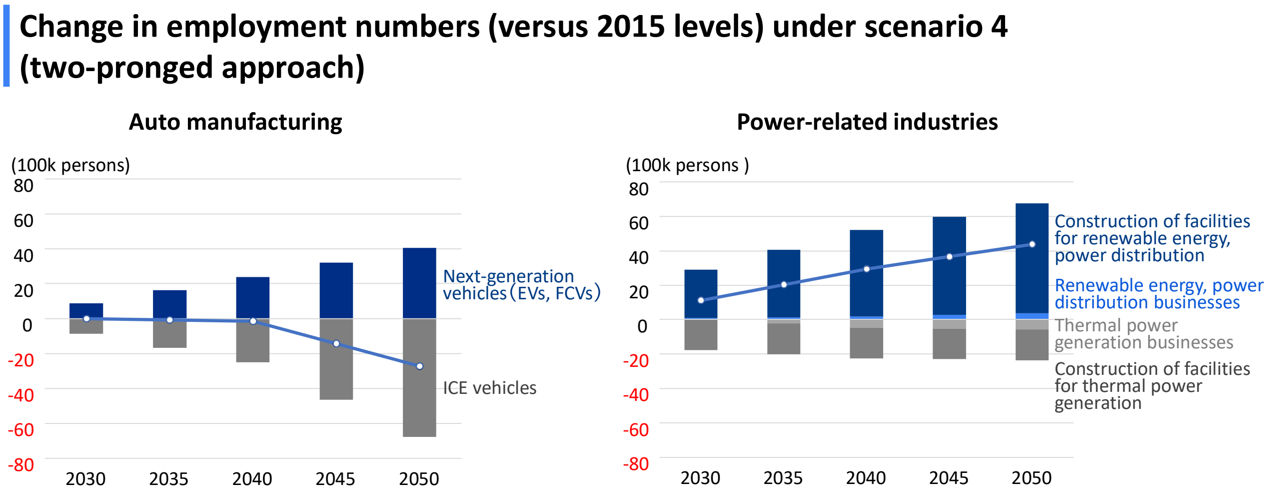
The results shown above are only estimates for decarbonization under scenario 4 (two-pronged approach). This type of industrial restructuring will not happen of its own accord as Japan decarbonizes. To achieve this type of structural change, Japan will need to undergo a transition in employment at the right time.

Figure 2-8 shows changes in employment in the auto manufacturing and power industries (including facility construction and parts production) under the same scenario 4 (two-pronged approach). As with the change in value added, in the auto manufacturing sector, there is a rapid shift into next-generation vehicles from 2040, so Japan needs to undergo a substantial shift in employment from ICE vehicles to next-generation vehicles. However, ultimately this will result in fewer workers employed to make next-generation vehicles compared with ICE vehicles because there will be fewer parts needed per finished car. By 2050, the auto manufacturing sector alone will have lost 270,000 jobs.[9] In contrast, in the power industry, construction of renewable energy and other facilities will drive employment such that overall there will be more people employed compared with 2015. By 2050, there will be 440,000 more jobs than in 2015.

We highlight here that this labor transition is not limited to a single industry or within a business type. People working in fuel procurement planning and shipping operations for liquid natural gas (LNG) thermal power facilities need very different skills to people working on the operations and maintenance services needed for wind power generation facilities. For Japan to encourage labor mobility within and between industries, we need to visualize the tasks and skills breakdown in industry types where employment demand will rise as the country decarbonizes, and design systems to help promote a smooth transition of employment away from mature areas and into growth areas. Japan needs to take urgent steps to prepare for this industry restructuring and employment transition, starting well before 2030 when zero-carbon technologies are rapidly rolled out across society.

[9] For the broader auto-related industry, which includes cargo/passenger transportation and sales/maintenance as well as auto manufacturing, estimates suggest there will be a substantial drop in employment from the current 5.41 million jobs to 3.1 million jobs in 2050.

Fig. 2-8: Widening employment gap even within same industry

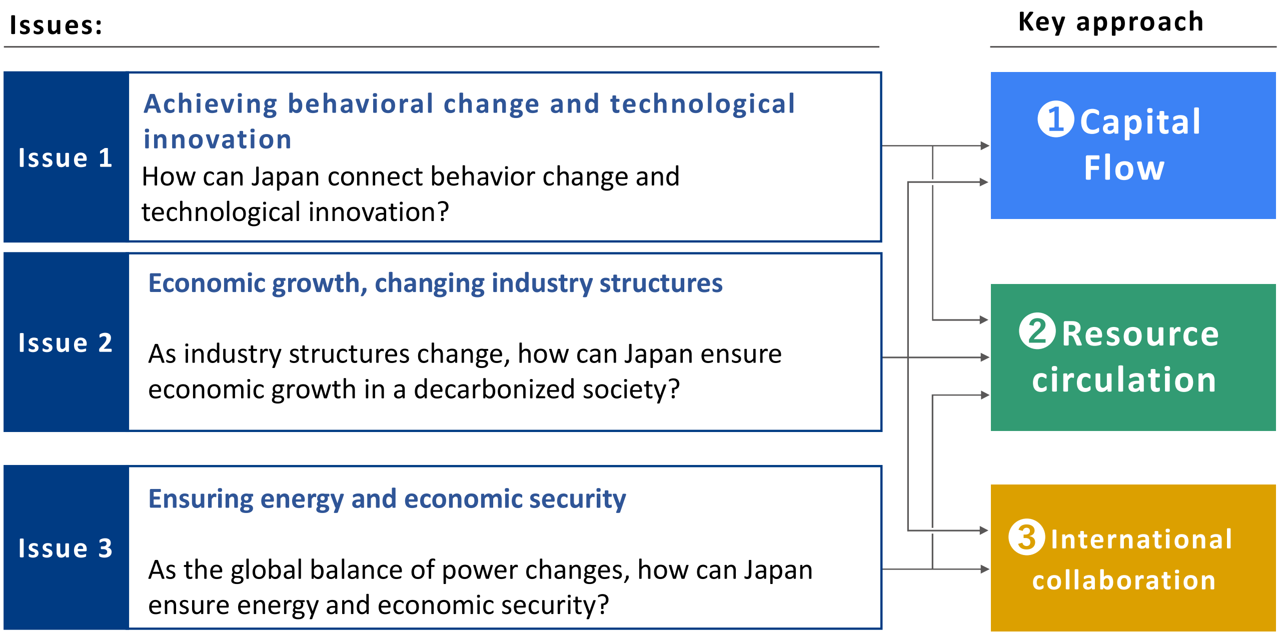



Source: MRI

# 3. Capital flows, resource circulation, and international collaboration are the keys to a smooth transition

To achieve a smooth transition, Japan needs to find a way forward with the following issues discussed in the previous chapter: How can Japan connect behavior change and technological innovation? As industry structures change, how can Japan ensure economic growth in a decarbonized society? And, as the global balance of power changes, how can Japan ensure energy and economic security? These questions are not easy to answer. We propose three factors that we think provide a key approach for Japan: (1) capital flows, (2) resource circulation, and (3) international collaboration.

**Fig. 3-1: Relationship between issues with transition and capital flows, resource circulation, and international collaboration**




Source: MRI

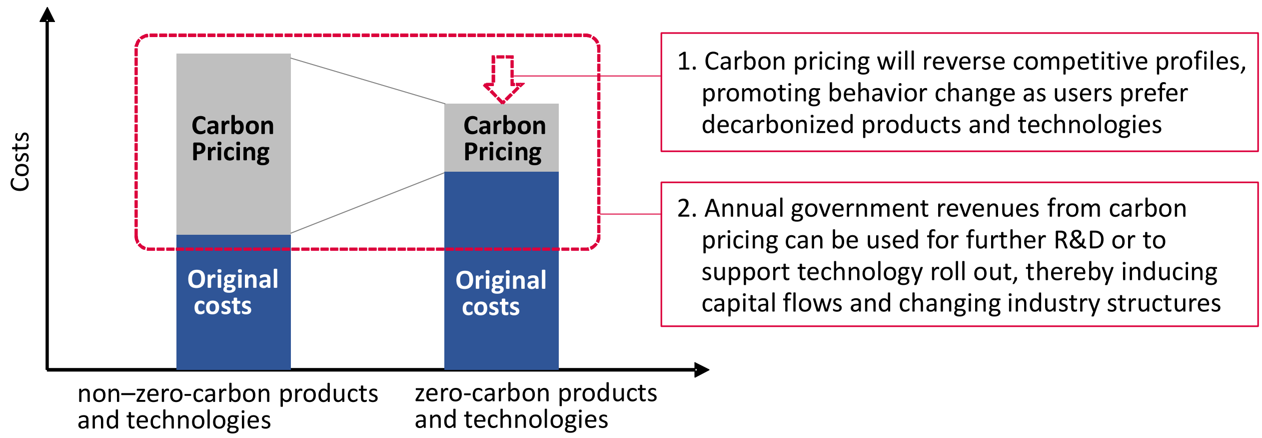
## 3.1. Capital flows

### Carbon pricing is a powerful tool for capital flows, impacts both behavior change and technological innovation

To achieve a smooth transition to carbon neutrality, it is essential to stimulate investment and support for products and technologies that contribute to decarbonization and to promote capital flows. Carbon pricing involves assigning a price to carbon and putting the cost burden on emitters; as such, it is an effective mechanism to promote reduced emissions and a powerful tool to drive capital flows. Figure 3-2 shows the expected outcomes from the introduction of a carbon pricing system: (1) carbon pricing indirectly lowers the costs of zero-carbon products and technologies relative to non–zero-carbon products and technologies whose prices reflect carbon pricing, thus reversing cost competitiveness profiles and driving changes in demand-side consumption patterns, and (2) carbon pricing to support R&D into, and faster uptake of, innovative products and technologies results in redistribution of government revenues, thereby increasing market predictability and changing industrial structures.

This shows that carbon pricing can drive behavior change and technological innovation and promote technology roll out across society, which may lead to a shift to more decarbonized consumption and industrial structures.

**Fig. 3-2: Visualizing how carbon pricing will reverse competitive profiles and change structures**




Source: MRI

## Need to price carbon at the right level to induce behavior change

First, let's look at the effect of carbon pricing to promote demand-side behavior change. Various factors have combined to drive up energy costs, such as the sharp rise in fuel prices because of the situation in Ukraine. Against this backdrop, we conducted a questionnaire-based survey in March 2023 with consumers and companies to investigate how awareness of demand-side behavior change has changed in the current conditions and to get a better understanding of what impact carbon pricing would have on behavior change.

Figure 3-3 shows the relationship between tolerance of cost increases and electricity rates when switching to electricity from renewable energy sources (renewable electricity). Note that the results from questionnaire-based research conducted at three points in time (March 2021, April 2022, and March 2023) have been used for the tolerance to cost increases data. Electricity rates have been on an upward trajectory, but have been rising sharply since the start of 2022. At the same time, there was a decline in the percentage of both consumers and companies that could tolerate cost increases. Over the medium and longer term, renewable electricity may become more cost competitive when fossil fuel prices or wholesale electricity market prices rise, but at this stage with energy costs trending upwards, there are concerns over a slowdown in behavior change (such as switching to renewable electricity).

However, as we have previously reported,[10] our analysis also shows that power consumption per unit of GDP is lower in countries with higher electricity rates, so we think that appropriate energy costs act to accelerate the move to carbon neutrality. While future trends in energy costs are unclear, if carbon pricing can provide appropriate pricing signals and foster behavior change, this may lead to changes in consumption patterns and also changes to more zero-carbon industry structures.

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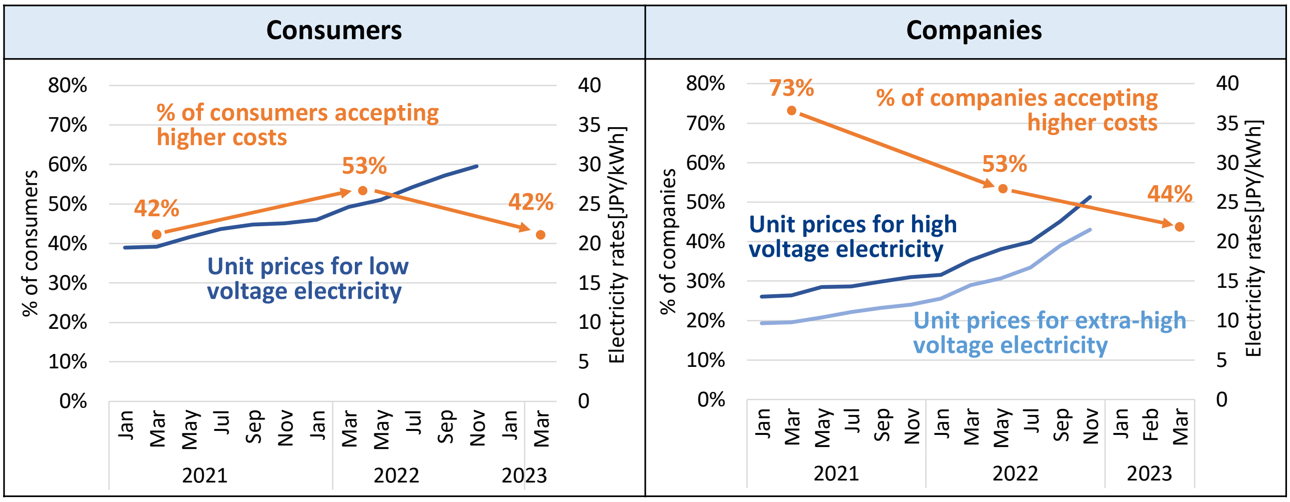
[10] MRI Economic Review, Future Outlook for Europe's Energy Crisis and Ideas for Japan (Japanese only), 29 November 2022, https://www.mri.co.jp/knowledge/insight/20221129.html

**Fig. 3-3: Reduced tolerance of higher renewable energy purchasing costs as electricity rates rise**




Source: MRI

This begs the question, what level of carbon pricing would effectively and efficiently trigger behavior change? Figure 3-4 shows the results of an analysis of four different behavior changes that investigates various carbon prices and the percentage of demand-side users prompted to change behavior if the carbon price is passed on directly to energy costs. Assuming a carbon price of JPY2,000/$tCO_2$,[11] based on government materials, around 15–40% of both consumers and companies would be prompted to change behavior, although the results differ according to the type of behavior change. This suggests that this price would not be enough to produce the zero-carbon effects expected through behavior change during the transition to carbon neutrality. If the carbon price is increased to \$140/$tCO_2$ (approx. JPY18,000/$tCO_2$), which is the price for advanced economies in 2030 under the Net Zero Scenario in the World Energy Outlook 2022 from the IEA, the percentage of demand-side users prompted to change behavior, such as electrification or rapid replacement with energy-saving products, would rise to 65–70%. This shows that increasing the carbon price can induce behavior change.

The change in the percentage of demand-side users prompted to change behavior when the carbon price was increased peaked out at a price of around JPY20,000/$tCO_2$, suggesting we cannot expect a dramatic increase in behavior change at carbon prices above this level. Therefore, Japan should make reference to international carbon pricing levels so that the country sets a carbon price at a level that allows industry to remain competitive while also maximizing the behavior change effects.

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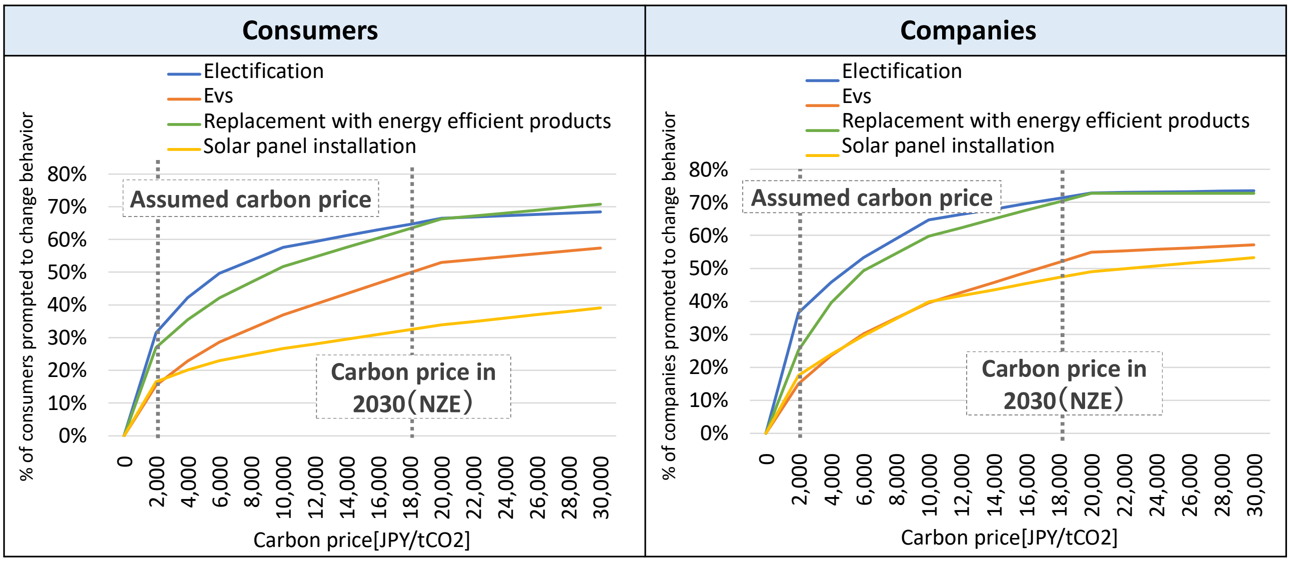
[11] The Japanese government will issue JPY20 trillion in transition bonds over the next ten years to finance the transition to a decarbonized society and expects to fund this from carbon pricing (emissions trading, carbon levy). The carbon price will be around JPY2,000/$tCO_2$, assuming that total GHG emissions of around 10 billion $tCO_2$ will be needed to recover this JPY20 trillion.

**Fig. 3-4: Carbon pricing produces different effects depending on the price level**




Source: MRI

## Investment will need to increase after 2030 for roll out across society

To fulfill scenario 4, where carbon neutrality is reached through a two-pronged approach of behavior change and technological innovation, Japan needs to build up investment to a certain level. However, to achieve scenario 4, Japan must create an environment that supports voluntary investment by companies over the medium and long term. For companies to invest enough to achieve the goal of carbon neutrality, we need the involvement of government in a leading role as well as greater clarity on the medium- and long-term direction of carbon prices in order to improve predictability for private investment. This also assumes high expected rates of return on investments in relevant fields.

So, what is the total amount of investment needed to achieve scenario 4? As in section 2.3., we created future industrial input-output tables and analyzed the economic ripple effects to estimate the investment in R&D and fixed capital formation (investment in capital expenditure and construction: public and private sectors) needed to achieve scenario 4. Fixed capital formation was derived for each industry using the value added following each scenario for economic ripple effects and the percentage of value added accounted for by fixed capital formation. For R&D investment, we interrogated the R&D productivity figures by industry (value added/R&D stock) in the JIP database at the Research Institute of Economy, Trade and Industry (RIETI)[12] and used this information[13] to calculate the value of R&D stock needed to achieve the value added, which allowed us to calculate R&D investment (flow).[14]

Figure 3-5 below shows the amount of investment needed to achieve the various scenarios. According to our calculations, the cumulative total over the 30-year period between 2020 and 2050 would be around JPY140 trillion under scenario 1, but a minimum of JPY320 trillion to achieve scenario 4. The results also made clear that the amount needed to achieve scenario 4 will need to increase from 2030 as technological innovation and roll out across society go into full swing, rather than investment focused on behavior change up to 2030.

According to midpoint calculations in the Clean Energy Strategy unveiled by the Ministry of Trade, Economy and Industry (METI) in May 2022, Japan will need to invest JPY150 trillion in decarbonization over the next ten years, from both the public and private sectors. However, our estimates suggest that double this level of investment will

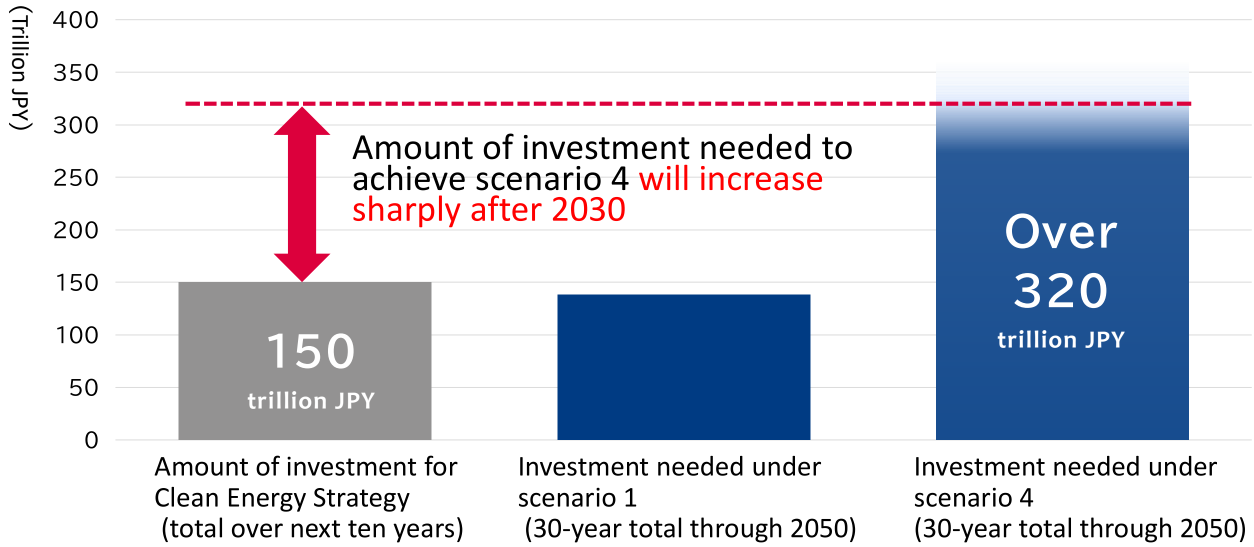
12 https://www.rieti.go.jp/en/database/JIP2021/index.html

13 Due to the disparity between the industry classifications used in this study and the JIP Database, the value-added productivity of the electricity industry is applied for renewable energy-related industries, while that of the automobile industry is applied for EVs and FCVs.

14 In many previous research projects, R&D investment accumulates as R&D stock and it is assumed that R&D stock naturally decreases at a fixed percentage. The rate of natural decrease has been typically set at 15%, as in research by Griliches and Mairesse (1984) or Hall and Mairesse (1995). We have followed this assumption in this report.

be needed through to 2050.[15] To improve expected rates of return, Japan needs to increase earnings while at the same time reducing risk. For this to happen, the government needs to be clear about its policy direction in the relevant fields over the medium and long term, and then work on the predictability of subsequent system designs.

**Fig. 3-5: Investment needed for decarbonization will increase after 2030**




Notes: The required investment shown here (30-year total through 2050) is a rough estimate calculated from an analysis of ripple effects using future industrial input-output tables created in line with the assumptions for each decarbonization scenario. These calculations only include renewable energy, next-generation vehicles, general-purpose machinery, electrical machinery, etc. During the process of decarbonizing, there will be ripple effects on other types of industry, such as telecommunications or information services, but these are excluded from the calculations of investment. Note that the figures may differ from those in the Clean Energy Strategy because of the approach and scope of coverage used.
Source: MRI

## 3.2. Resource circulation

### Japan must secure resources for a smooth transition

Countries around the world are enacting various laws on economic security amid rising geopolitical tensions on the global stage. Japan enacted the Economic Security Promotion Act in May 2022, part of which designated resources from among the 11 types of specified critical materials as being essential for the transition to decarbonization. The list included critical minerals, storage batteries, natural gas, and permanent magnets.

Countries around the world are acutely aware of the importance of critical minerals. In February 2022, the US Geological Survey (USGS) released a new list of 50 mineral commodities critical to the US economy and national security and which have a supply chain vulnerable to disruption. In March 2023, the European Commission announced the Critical Raw Materials Act and set benchmarks for domestic capacities within the EU along the supply chain that covers extraction, processing, and recycling. The lists of minerals designated as critical by Japan, the US, and the EU are generally the same, and demand (both direct and indirect) for almost all these minerals is expected to increase as countries transition to carbon neutrality. This includes cobalt, nickel, lithium, and rare earth elements that are essential for storage batteries as well as other minerals that will be needed for electrification, such as gallium and tungsten used in power semiconductors and cemented carbide cutting tools. However, in terms of

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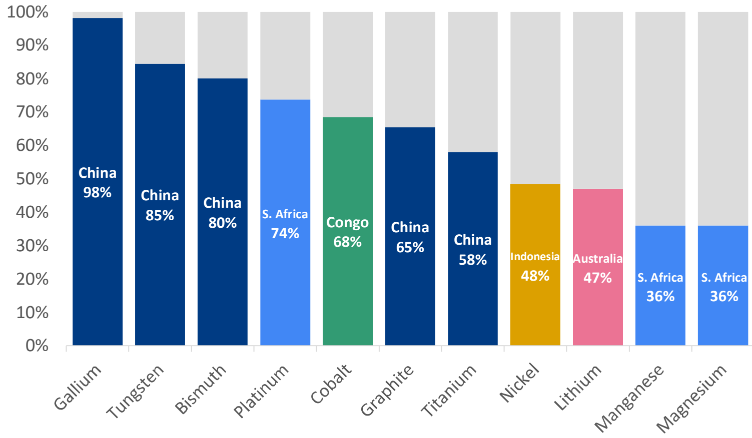
[15] Note that the scope of our estimates here differs from the calculations in the Clean Energy Strategy For example, housing & buildings is included in the Clean Energy Strategy under the category "end-use decarbonization" but is excluded from our estimates, while the category "construction of power transmission and distribution facilities/institutions related to decarbonization" is included in our estimates, but not in the Clean Energy Strategy. The investment needed for this latter category is substantial—we estimate around JPY240 trillion (total over the next 30 years), versus the approx. JPY60 trillion investment for energy supply decarbonization (total over the next ten years) in the Clean Energy Strategy. Because of the difference in scope in the two sets of calculations, our estimates suggest lower total investment through 2030 compared with the Clean Energy Strategy, but a strong increase in the required investment thereafter.

the resources for the metals defined by all countries as essential, the markets are oligopolies dominated by one producing country, and China has a particularly high production share (Figure 3-6). Japan must secure the necessary resources for a smooth transition to carbon neutrality at the same time as other countries around the world are focusing on economic security and designating the resources and products needed for decarbonization as strategic materials.

**Fig. 3-6: Production of critical mineral resources is dominated by an oligopoly or China**

**Production share for minerals designated as critical resources by Japan, the US, and EU**

| Basis for designation as critical minerals | |
|---|---|
| **Japan** | 35 minerals designated as critical minerals, one of the categories of specified critical materials included in the Economic Security Promotion Act (enacted in May 2022) |
| **EU** | 16 strategic raw materials included the Critical Raw Materials Act announced by the European Commission in March 2023 |
| **US** | US Geological Survey (USGS) released a new list of 50 critical mineral commodities in February 2022 |




* Rare earth metals, platinum group metals other than platinum, and germanium are also on the critical minerals lists in Japan, the US, and EU, but are omitted from this figure because of a lack of USGS data on production volumes
Source: MRI, from USGS data

## $CO_2$ emissions reductions through resource circulation need to be appropriately quantified

Given this background, resource circulation is an important approach for a nation like Japan that lacks its own natural resources. In MRI research published in February 2023,[16] we highlighted the fact that Japan will need more than just metal resources to become carbon neutral. We defined " natural resources vital for renewables" and "scrap plastic and steel scrap resources vital for the materials industry to become carbon-neutral resources" and showed how proactive circulation of these carbon-neutral resources could be the key to both economic security and decarbonization. Decoupling resource imports from economic growth and moving from a linear economy (one-way economic model of mass production and mass consumption) to a circular economy is also important in the context of decarbonization.

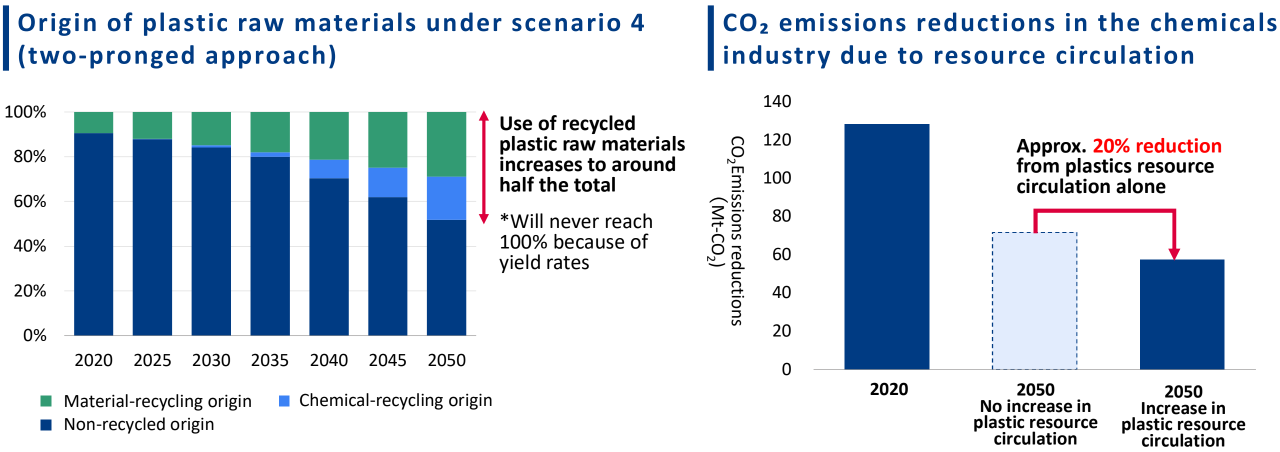
However, the concept of a circular economy goes beyond resource circulation and includes different business models and usage formats, such as pooling and sharing. Depending on the measures implemented, there are concerns that the circular economy concept could backfire, as there is a high risk that GHG emissions actually increase rather than decrease.[17] Japan needs to take a more cautious approach when assessing individual initiatives and to quantify $CO_2$ emissions reductions through resource circulation.

One example touched on in previous research[18] is resource circulation of plastics, where decarbonization is difficult and recycled material usage only amounts to around 10% of the total. As Japan decarbonizes, there will be greater electrification of vehicles and the private sector, which is expected to result in a substantial drop in demand for gasoline and other fuel oils. However, there will still be a certain level of domestic demand for plastics, so the change in demand structures as Japan decarbonizes will have a huge impact on the petrochemical industry.

[16] Becoming a Carbon Neutral Resource-Driven Nation (Japanese only), *MRI Monthly Review*, February 2023 issue, https://www.mri.co.jp/knowledge/mreview/202302.html
[17] Unpacking the Essential Requirements for the Circular Economy to Lead to Decarbonization (Japanese only), National Institute for Environmental Studies, https://www.nies.go.jp/whatsnew/20211215/20211215.html
[18] The Future of Resource Circulation through Technology and Collaboration, (Japanese only), *MRI Monthly Review*, March 2023 issue, https://www.mri.co.jp/knowledge/mreview/202303.html

To work out the $CO_2$ emissions reductions accompanying these structural changes, we need to take an integrated approach to quantification that spans all sectors, rather than simply looking at petrochemical producers. Figure 3-7 shows the results of this cross-sector analysis. Even if there is significant expansion of plastics circulation and progress in material recycling and chemical recycling, yield rates mean that plastic manufacturing cannot use 100% recycled materials. However, we can see a difference of around 20% in $CO_2$ emissions reductions in the chemicals industry, in 2050 depending on whether resource circulation is in place or not. Resource circulation may be one realistic solution in the materials industry where emissions reductions are difficult to achieve. Japan needs keep making progress while monitoring the outcomes from individual measures.

**Fig. 3-7: Need to quantify the $CO_2$ emissions reductions from resource circulation**




Source: MRI

## 3.3. International collaboration

### International cooperation also increasingly important for economic security

Climate change is a global issue and all countries need to work to reduce their GHG emissions. Emissions in Asia account for some 60% of the global total,[19] so Asia's transition to carbon neutrality is extremely significant for combating climate change. Japan's emissions account for several percent of the global total. As well as reducing domestic emissions, we think Japan also needs to think about how its decarbonization technologies can help nations in Asia and elsewhere to reduce their emissions.

Japan's domestic market could start shrinking due to population decline and other factors. As such, international collaboration is a key point for Japan if it is to grow its economy. Through its Basic Policy on Green Transformation (GX), the Japanese government aims to stimulate economic growth by creating new demand and new markets in zero-carbon fields and making Japanese industry more competitive. For the future, Japan needs a concrete strategy of moving into growth markets around the world, with a particular focus on neighboring countries in Asia.

Economic security will also be impacted by the tides of change from decarbonization. Economic security encompasses a wide range of issues, but Japan may need to pay particular attention to the impact of decarbonization on supply chains. Because zero-carbon technologies need different resources/minerals and products compared with conventional energy systems, Japan will not be able to avoid structural change in resource-importing countries and manufacturing supply chains. We are now in a time when decarbonization measures are being directly woven into national strategies; we can see a real emphasis on economic security in the Green Deal Industrial Plan in the EU and the Inflation Reduction Act in the US. We understand that Japan is in a different position to other countries and regions, including the EU and US, but we also question how Japan is engaging with international collaboration.

[19] Asia emissions when categorized as one of the five continents. The other continents are the Americas, Europe, Africa, and Oceania.

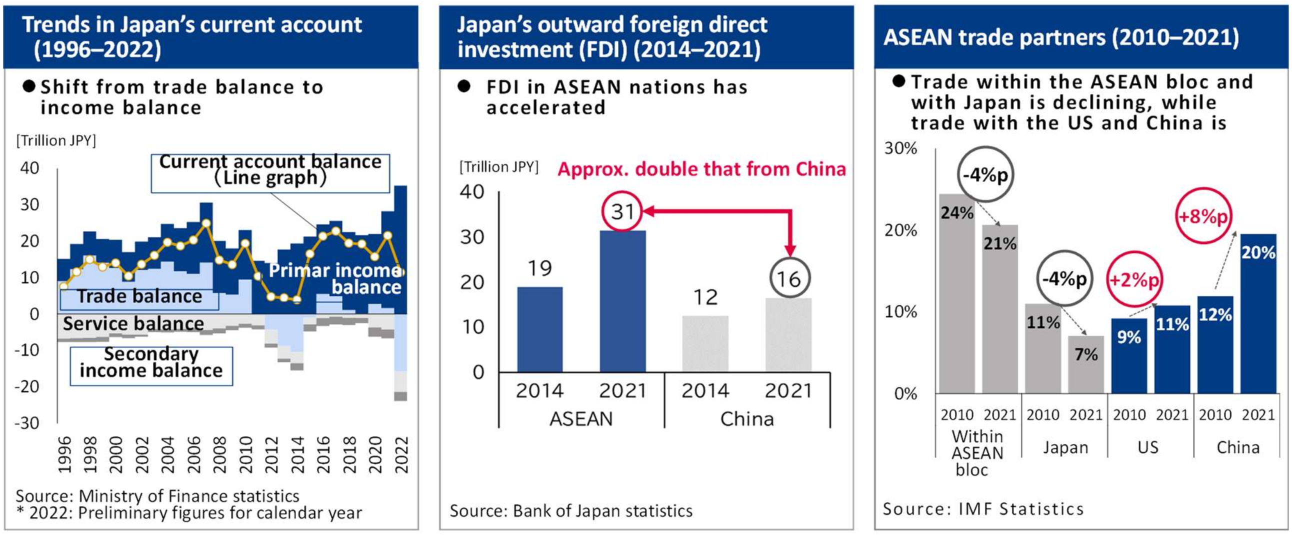
## Coordination with ASEAN nations increasingly important from an economic security perspective

Japan's current account balance, which acts as an international economic benchmark, has started to change in recent years. Until the mid-2000s, the trade balance meant Japan had a current account surplus. From the late-2000s, the current account stayed in the black mostly because of the primary income balance, including earnings from direct investments (Figure 3-8, left). In 2022, spiking fuel costs lead to an expanding trade deficit, but Japan maintained its current account surplus through a primary income balance in excess of JPY30 trillion.

Neighboring Asian nations have been some of the main targets of direct investment by Japan. Direct investment in ASEAN nations has picked up pace in recent years such that the balance of direct investment is now double that from China (Figure 3-8, center). For Japan, ASEAN nations are important targets for investment, while for ASEAN nations, foreign investment is essential for future growth. From a trade perspective, ASEAN nations have become more dependent on the US and China as trade partners in recent years (Figure 3-8, right). We think that supply chain strategies, including for decarbonization, will be an important agenda item for ASEAN nations as well as for Japan.

In the context of economic security, the US is promoting the idea of "friend-shoring," but relationships of trust between nations are extremely important for international collaboration. Surveys on expectations for Japan as an ASEAN partner have shown a high level of trust in Japan,[20] but rather than positioning itself as the leader when building relationships of trust, we think Japan may need to find a way forward in developing more equal partnerships. Japan also needs to take into account the diversity and distinctive traits of the nations that make up the ASEAN community. Collaboration between Japan and the neighboring ASEAN nations is becoming an increasingly important element for both sides.

**Fig. 3-8: Collaboration between Japan and ASEAN nations increasingly important**




Source: MRI, from statistics from Ministry of Finance, Bank of Japan, and International Monetary Fund (IMF)

## Using a GTAP model to quantify the impact of decarbonization on international trade

The introduction of a carbon border adjustment mechanism (CBAM) by the EU has prompted more and more countries to introduce carbon pricing. In this report, we analyze the impact of carbon pricing on international trade through a quantitative evaluation using a Global Trade Analysis Project (GTAP) model. The GTAP model is a basic general equilibrium system that links to a database on global trade relations for analysis. In our analysis, we use a GTAP-E model that has been fine-tuned for the energy sector.

We set two scenarios for analysis: a high-carbon-price one and business-as-usual (BAU) one. We evaluate the impact of the high carbon price on trade from the difference in the results for these cases in 2050 (Figure 3-9). The high-

[20] Seah, S. et al., The State of Southeast Asia: 2022 (Singapore: ISEAS-Yusof Ishak Institute, 2022)

carbon-price case is a scenario where a high carbon price is introduced but the structural changes needed for decarbonization are not made. Details of the analytical steps are as shown below.

(1) Set common parameters for both cases (e.g., population, GDP, resource prices) as exogenous variables.

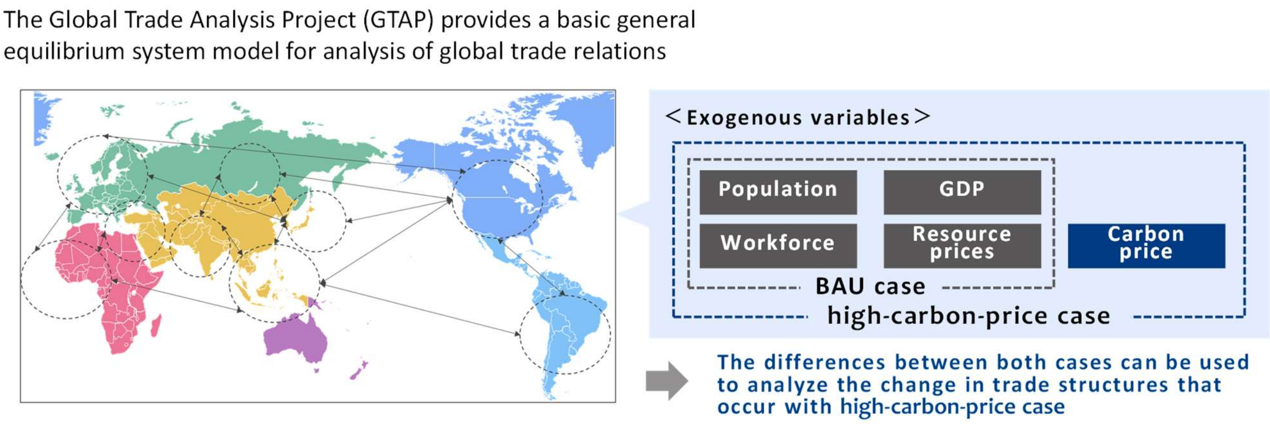
(2) Set the carbon price for the high-carbon-price case at the same level as in the Net Zero Scenario from the IEA.

(3) Use the GTAP model to analyze trade structures in the BAU case, based on the exogenous variables in step (1).

(4) Use the GTAP model to analyze trade structures in the high-carbon-price case, based on the exogenous variables in steps (1) and (2).

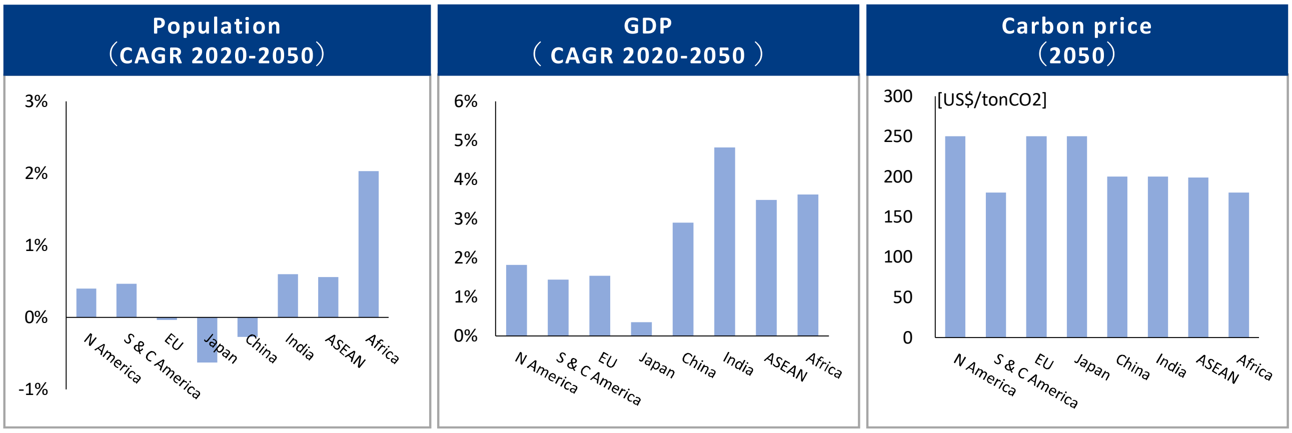
(5) Evaluate the impact of decarbonization (carbon pricing) on international trade from the difference in the results of steps (3) and (4)

**Fig. 3-9: Focus on differences between high-carbon-price decarbonization and BAU**




Source: MRI

**Fig. 3-10: Main assumptions for analysis (population, GDP, carbon price)**




* GDP based on MRI assumptions

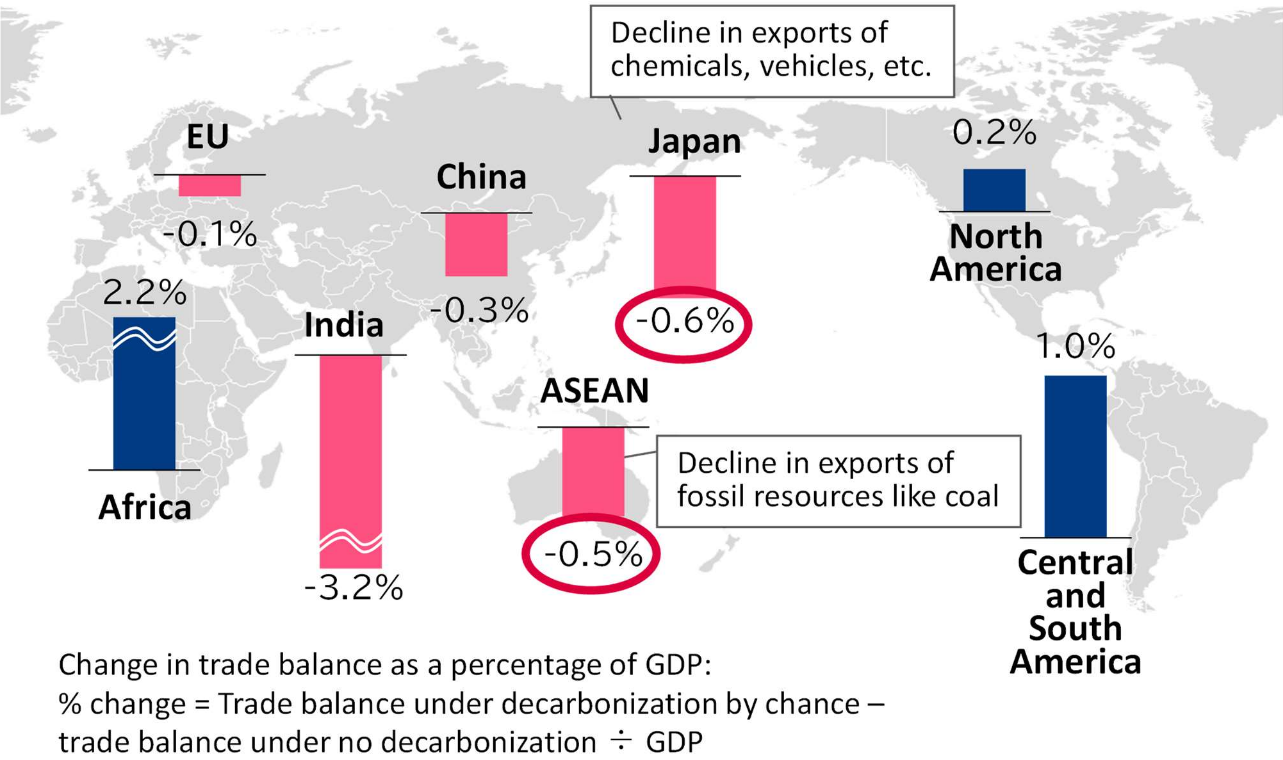
Source: MRI, from UN population statistics, IEA World Energy Outlook 2022

## High-carbon-price case: concerns over industrial competitiveness and economic security for both Japan and ASEAN nations

In the world described by the high-carbon-price case where energy systems do not go through the structural changes needed for decarbonization, there are negative consequences for the trade balances at Japan and at ASEAN nations (Figure 3-11). The model confirms that Japan becomes less competitive, particularly in the chemicals and automotive fields, and that export value declines. In ASEAN nations, although carbon prices are not as high as in Japan, there are huge negative impacts on fossil resources companies, particularly for coal, and the trade balance also declines. This analysis shows that energy costs, including carbon prices, are a driver of change in global trade structures.

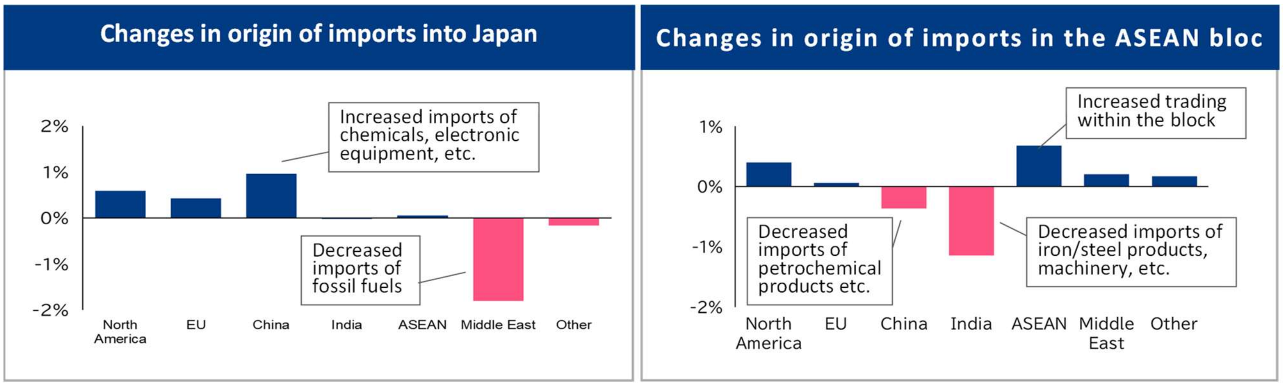
Decarbonization impacts more than just industrial competitiveness. A change in trade structures implies a change in partner countries for imports and exports. For Japan, the value of fossil fuel imports will decline, so the country will be less reliant on the Middle East, but at the same time the value of chemicals, electronic equipment, and other imports from China will increase (Figure 3-12). The results for ASEAN nations show that trading within the bloc will increase, leading to a decline in imports from India and China. However, most of the decline in imports from China is for petroleum products, and readers should note that there is actually an increase in import value for steel and chemical products.

**Fig. 3-11: High-carbon-price decarbonization negative for Japanese and ASEAN trade balances**




Source: MRI

**Fig. 3-12: Decarbonization will also impact economic security through changes in trade structures**




* Shows the difference (percentage point) in the countries of origin for imports under the high-carbon-price case and the BAU case by 2050
Source: MRI

## Stronger relationships with ASEAN nations through decarbonization can lead to economic growth and economic security on both sides

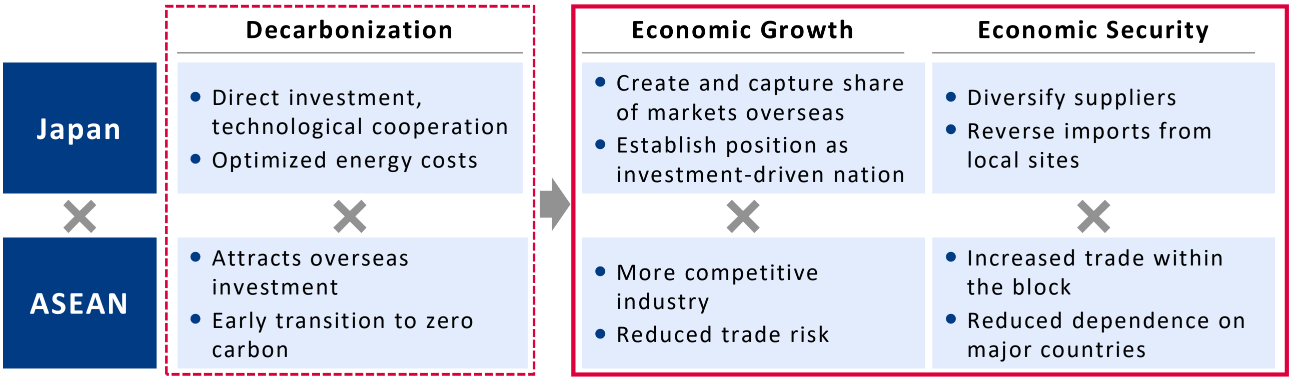
Energy is the lifeblood of industry and the cost of energy influences industrial competitiveness, while also having effects on economic security. Japan lacks fossil resources and has limited land area for its population size. It is therefore important for Japan to think beyond its borders and aim to optimize energy costs. ASEAN nations may face similar challenges to Japan, given their reliance on coal and relatively high population densities. Japan could build cooperative relationships with ASEAN nations in many different areas, including development of decarbonized fuel technologies (e.g., ammonia), enhanced purchasing power when importing from other countries, increased uptake of next-generation solar power, or Japanese nuclear power technologies designed to withstand earthquakes. For ASEAN nations, a rapid transition to carbon neutrality would also reduce trade risk over the medium and long term.

In the future, we think it will be increasingly important for Japan to invest directly in ASEAN nations, including from the perspective of energy cost optimization. Japan needs to re-orient itself away from its traditional role as a trade-driven nation and strengthen its position as an investment-driven nation. In order to drive economic growth for both Japan and ASEAN nations, we think Japan will need to utilize the technological capabilities the country has developed thus far, identify partner countries and fields for collaboration amongst the diverse ASEAN community, and achieve highly efficient investments and improved productivity.

From the perspective of resource circulation as well, an effective approach may be to look beyond Japan's borders and collaborate overseas. Even if Japan cannot avoid being dependent on specific resource-producing countries, economic security may be improved if the resources, once imported, are then recirculated. Another option is to rebuild supply chains through collaboration with the ASEAN nations that are Japan's geographical neighbors. Through the Regional Comprehensive Economic Partnership (RCEP), trade relations between China and ASEAN nations are expected to change through the elimination or reduction of tariffs on imports. This trade agreement may also make resource circulation within the ASEAN block even more important.

It takes time to rebuild supply chains, but Japan needs to work steadily on building collaborative relationships with one eye on the ripple effects on economic security from this type of collaboration. For Japan, the key to new growth lies in building energy systems beyond Japan's domestic borders and shifting to a role as an investment-driven nation. Using decarbonization as a starting point, we look for Japan and ASEAN nations to further their relationships of trust and build complementary relationships that contribute to economic growth and economic security.

**Fig. 3-13: Use decarbonization as a starting point for building mutually complementary relationships based on trust, which will also contribute to economic growth and economic security**




Source: MRI

## 4. In conclusion: Achieving a smooth transition

In this report, we focus on how Japan needs to transition to carbon neutrality by 2050 and propose a number of points that will help Japan achieve a smooth transition to a decarbonized society without damaging economic security and economic growth.

As of May 2023, amidst energy market turmoil and ongoing global geopolitical tensions, the path to carbon neutrality still looks uncertain. In the face of such mounting challenges, we need to define a vision for a realistic transition to carbon neutrality that does not damage economic security or economic growth.

In this report, we highlight how important it is for Japan to find a way forward in the following issues if the country is to achieve a smooth transition: How can Japan connect behavior change and technological innovation? As industry structures change, how can Japan ensure economic growth in a decarbonized society? And, as the global balance of power changes, how can Japan ensure energy and economic security? We then propose three key approaches: (1) capital flows, (2) resource circulation, and (3) international collaboration.

For (1) capital flows, if Japan is to transition smoothly to a zero-carbon society, the country must promote capital flows into the areas that need it and decarbonize industry structures and the economy. Carbon pricing may promote demand-side behavior change by making the price of carbon apparent, while also supporting the investment needed from government revenues for decarbonized technology R&D and social roll out. It has the potential to act as a bridge between early-stage measures for behavior change and the technological innovation required over the medium or long term. Japan needs to set an appropriate carbon price, making reference to international levels and the amount of investment needed, and improve predictability over the medium and long term.

For (2) resource circulation, this approach is important because Japan needs to secure zero-carbon resources while also decarbonizing materials fields. Japan lacks natural resources, but the country needs to reduce imports of the resources needed and lessen the risks to economic security as decarbonization changes the patterns of energy use and economic security. Resource circulation may also be an effective way to reduce $CO_2$ emissions in hard-to-abate materials fields. Japan needs to bind its energy policies and resource circulation policies more closely together.

For (3) international collaboration, it will be increasingly important for Japan to work together with ASEAN nations in the context of economic security and economic growth, as well as decarbonization. We expect closer ties between Japan and ASEAN nations to create more mutually complementary relationships. Through these closer ties, Japan needs to build energy systems beyond its domestic borders and re-orient itself away from its traditional role as a trade-driven nation, repositioning itself as an investment-driven nation that leverages its technological capabilities.

The term “carbon neutral” has only been part of Japanese government policy for the past three years. During that time, the international geopolitical situation has completely changed and Japan now finds itself in an increasingly difficult position. However, the time is ripe for Japan to move on from discussions of carbon neutrality and start taking action. The country needs to actually take steps to achieve the ideal transition to a decarbonized future.

## Background material

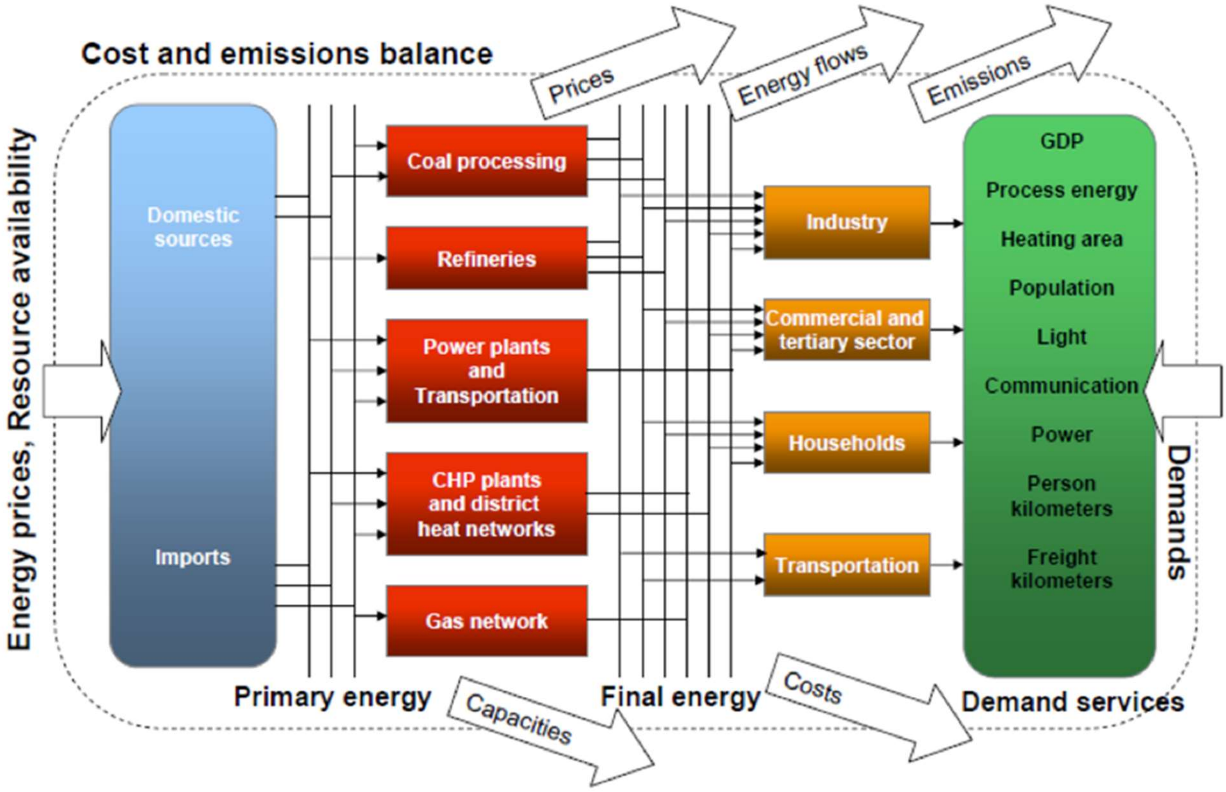
### Overview of the TIMES model of energy supply/demand

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 (commercial and households buildings, transport, and industry). 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.

### Overview of the TIMES model




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

## Main prerequisites and results by scenario

In Chapter 2 of this report, we developed four scenarios for the future and conducted an analysis using the TIMES model of long-term energy supply/demand (described above) and the PyDis model of electricity supply and demand. The table below shows an overview of the main parameters set for each scenario. Please refer to the separate dataset that shows other main prerequisites and calculation results.

## Main parameters set for each scenario

| | | | Scenario 1: current trendline | Scenario 2: reduced demand | Scenario 3: technological innovation | Scenario 4: two-pronged approach |
|---|---|---|---|---|---|---|
| View on carbon constraints | | | **No constraints in model, decarbonization by chance** | **Emergence of carbon constraints equivalent to WEO's 2022 NZE (10 years earlier)** | **Emergence of carbon constraints equivalent to WEO's 2022 NZE** | **Emergence of carbon constraints equivalent to WEO's 2022 NZE (10 years earlier)** |
| Macro framework assumptions | | | National Institute of Population and Social Security Research assumptions used for population and household numbers. Fuel prices set based on World Bank and WEO 2022 figures. MRI estimates used for actual GDP, forex rates that form the basis of service demand estimates. (Assume lower growth rates compared with Sixth Strategic Energy Plan) | | | |
| Resource circulation | | | Certain amount of progress due to economic rationality | | Systematized resource circulation allows high recovery levels | |
| Power | Nuclear power | | Same for all scenarios and based on MRI estimate: 22GW in 2050.<br>No assumption of new builds/replacements but extends operational life to take into account shutdown periods. | | | |
| | Solar | Upper limit | **116GW**<br>(Home 17GW, business 99GW) | **260GW**<br>(Home 45GW, business 214GW)<br>*Based on 260GW reference from Strategic Energy Plan. | **404GW**<br>(Home 120GW, business 284GW)<br>*Assumes technological innovation, e.g., perovskite solar batteries, based on Ministry of Environment zoning research. | |
| | | Cost | **JPY170,000/kW** (home JPY230,000/kW)<br>*Cost Verification Working Group's assumptions for 2030 | | **JPY100,000/kW**<br>*Cost Verification Working Group's cost reductions from 2020 to 2030 extended through to 2050 | |
| | Wind | Upper limit | **62GW**<br>(Onshore 40GW, offshore 22GW) | **90GW**<br>(Onshore 45GW, offshore 45GW)<br>*Based on reference values, public/private discussions | **135GW**<br>(Onshore 45GW, offshore 90GW)<br>*Onshore still based on reference values, offshore based on public/private discussions on industry targets | |
| | | Cost | **JPY250,000/kW**<br>*Cost Verification Working Group's assumptions for 2030 (offshore: JPY510,000/kW) | | **JPY150,000/kW**<br>*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**<br>*Set at quite high cost levels | | **JPY30/Nm3 (S3), JPY20/Nm3 (S4)**<br>*With reference to government targets, S3 assumes tighter global supply/demand | |
| Hydrogen direct reduction (H-DR) steel | | | **Assume zero**<br>*No technological innovation, current steelmaking methods still in use | | **Assumes costs at same level as current blast furnace steel, starts being introduced in 2045**<br>*Based on values in paper from Lund University | |
| Next-generation automobiles | | | **Costs in 2030 maintained for both EVs, FCVs**<br>(EV just under JPY3mil, FCV just under JPY4mil) | | **Costs reduced to same level as ICEV for both EVs, FCVs**<br>(Around JPY2mil) | |

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