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Abstract

As efforts to address climate change advance globally, Japan has also stated that it aims to significantly reduce CO2 emissions by FY2030 with stable economic growth, under the carbon neutrality target for 2050. This paper presents the main challenges facing Japan's economy in the process of transitioning to a decarbonized society. It introduces the facts on energy conservation and decarbonization, the hypothetical scenarios analysis on energy prices, and the efforts of industry.

Until the early 1990s, Japan's progress in decarbonization in terms of CO2 emissions per real GDP was amongst the most remarkable in the world. Since then, it has been overtaken by advanced European countries due to a stagnation in energy conservation under low growth domestically and the slow decarbonization of energy sources following the Great East Japan Earthquake. Japan's current situation underlines once again that the orderly transition to a decarbonized society is not an easy task.

In Japan, (1) economic growth during the transition period could be significantly affected by the cost of installing renewable energy in the diffusion process and the trend of procurement costs of existing fossil fuels. On the other hand, (2) efforts and new investments toward decarbonization have the potential to improve the productivity and growth rate of the Japanese economy through technological innovation and the increased corporate propensity to spend, capturing new demands in the global market. In order to realize the positive progress of (2), it is also important for Japan's society as a whole to enhance its responsiveness in adapting to structural change, such as through increased capital and labor mobility between different sectors. Since these efforts are likely to take a considerable amount of time, the public sector is expected to provide long term support for proactive moves by firms and others.

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1. Introduction

The issue of climate change is one that will have broad social and economic impacts in the long term, both domestically and internationally. As the problem also creates what are known as "negative externalities" in economics, efforts to reduce emissions of greenhouse gases (GHG)—especially CO2, which accounts for the majority of emissions—are being made globally under international frameworks such as the Paris Agreement (Figure 1). This trend is continuing even as global energy prices are rising due to the current situation in Russia and Ukraine[1].

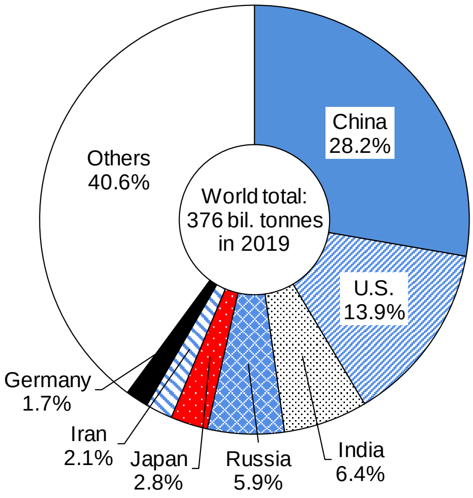
Japan has also committed to its long-term GHG emission reduction target of "achieving carbon neutrality by 2050" in the international framework. Aligned with this target, the government has also set an ambitious goal of reducing emissions by 46% in FY2030 (from FY2013 levels) and "...furthermore, we will continue to take on the challenge of reaching the 50% goal." Various public and private sector initiatives are underway in order to achieve this goal.

(Figure1) Current International GHG Reductions and Targets

(1) GHG reduction targets

	2030 targets			Carbon neutral targets
	Greenhouse gas emissions		CO2 emissions per real GDP	
		as of 2020		
Japan	-46% (from FY2013)	-18% (same)	--	2050
United States	-50 to -52% (from CY2005)	-22% (same)	--	2050
United Kingdom	-68% (from CY1990)	-50% (same)	--	2050
EU	-55% (from CY1990)	-34% (same)	--	2050
China	Peaking out	--	at least -65% (from CY2005)	2060
India	--	--	-33 to -35% (from CY2005)	2070

(2) World GHG emissions



Note: The targets of Japan are based on fiscal year. Figures are GHG emissions from energy in 2019.
Sources: UNFCCC; IEA[2021a], etc.

Climate change and the efforts to address it affect domestic and international economies and societies through various channels. The

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[1] For instance, in Europe, even after the Russian invasion of Ukraine, the importance of energy conservation and the expansion of renewable energy, which are initiatives to decarbonize the country, has been pointed out (European Commission [2022]).

Ministry of the Environment [2020] pointed out that effects of climate change is not limited to economic activities, but also extend to the natural environment, human health, and many other areas. When limited to the impact on economic activities however, many previous studies, such as those from NGFS [2020b] and the IMF [2020], have categorized the impact of climate change into two major transmission channels[2].

The first transmission channel is one in which an increase in extreme weather events has a direct impact on economic activity and corresponds to so-called "physical risk[3]." This can be further divided into "acute physical risk," in which extreme weather events and an associated increase in disasters affect the economy in the short term, and "chronic physical risk," in which a sustained rise in temperature affects aspects of the economy such as agricultural production and labor productivity (e.g. Batten [2018], Batten et al. [2020], NGFS [2021]).

The second transmission channel is one in which the economy is affected by changes in the behavior of economic agents in responding to climate change issues and corresponds to the so-called "transition risk." For example, if the energy supply-demand balance tightens as investment in fossil fuel development is curbed, or if use of renewable energy expands without a sufficient drop in costs—against a backdrop of tighter environmental regulations and heightened environmental awareness in Japan and abroad—higher energy prices could put downward pressure on economic activity. In addition, the introduction of carbon pricing and other measures will have a significant impact on industries that emit large amounts of CO2. On the other hand, there could be positive economic channels for the transition to a decarbonized society, such as increased technological innovation and capital investment toward decarbonization, which would lead to higher productivity in the macroeconomy as a whole.

This paper presents and discusses the main challenges and risks that

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[2] Research related to climate change is also ongoing in the field of economics. For details, see the Bank of Japan's Institute for Monetary and Economic Studies' special volume of the IMES Newsletter on "The Economics of Climate Change" (Institute for Monetary and Economic Studies, Bank of Japan [2021a, b, c, d, e]) and Aruga et al. [2022].

[3] The Task Force on Climate-related Financial Disclosures (TCFD) categorizes climate-related risks as "physical risks" and "transition risks" (TCFD [2017]).

Japan's economy is likely to face in the latter channel, i.e., in the process of transitioning to a decarbonized society. Since Japan has been lagging behind major European countries in its efforts to decarbonize, the rapid transition to a decarbonized society by FY2030 could have a significant impact on business activities and the macroeconomy. We think that this will be an important factor in the discussion of Japan's growth and productivity trends over the medium to long term. With regard to the former channel (i.e. physical risks), the increase in extreme weather events may amplify short-term fluctuations in the economy, and that medium- to long-term temperature increases may exert downward pressure on labor productivity growth in Japan, as in other countries (see Appendix 1).

The paper is organized as follows. First, in chapter 2, we compare Japan's historical and current decarbonization trends with those of the U.S. and major European countries using macroeconomic data since 1970, and then summarize the features of plans for the transition to a decarbonized society in the future, especially toward FY2030. Chapter 3 discusses the potential impacts of the transition to a decarbonized society on the economy, dividing them into two channels: (1) through changes in energy prices; and (2) through changes in productivity. The appendixes deal with the brief analysis related to the physical risks of climate change described above, in addition CO2 emissions during the COVID-19 pandemic.

2. Trends in decarbonization in Japan and features of the transition plan towards fiscal 2030

(1) Decarbonization trends in Japan

In discussing the economic implications of the transition to a decarbonized society, we look at the long term changes in Japan's progress toward decarbonization and see where we stand today. To compare Japan's current position with that of previous years and with other countries, we use "CO2 emissions per real GDP," adjusted for differences in the economic level of each country and time period[4].

In assessing "CO2 emissions per real GDP," it is useful to break this

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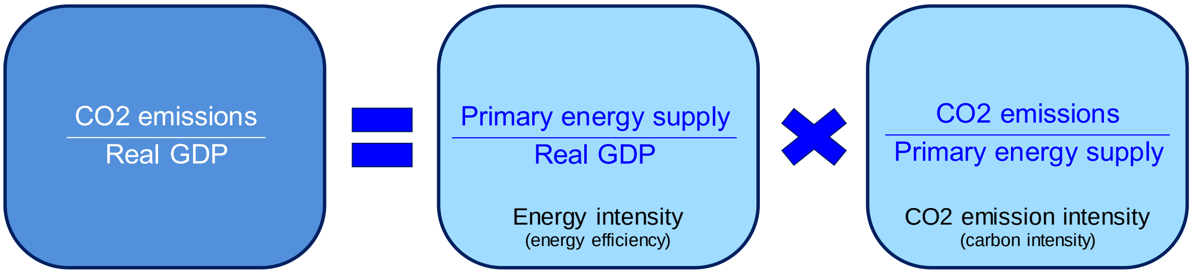
[4] Since CO2 accounts for about 90% of our country's GHG emissions, this paper discusses the reduction of CO2 emissions.

down into "energy intensity" and "CO2 emission intensity" (Figure 2)[5]. Energy intensity is the amount of energy used to produce one unit of real GDP, and is an indicator of "energy conservation." For example, installation of energy-efficient production equipment will decrease the energy intensity. On the other hand, the CO2 emission intensity shows the CO2 emitted to produce one unit of energy and is an indicator of the degree of decarbonization provided by an energy source. For example, if power sources shift from thermal power generation to renewable energy, the CO2 emission intensity will decrease. The progress of electrification and hydrogenation of energy sources in industries that use large amounts of fossil fuel-derived thermal energy for production, such as a material industry, will also lead to a decrease in CO2 emission intensity.

(Figure 2) Decomposition of CO2 Emissions Per Real GDP



Compared to the U.S. and many countries in Europe, Japan was making substantial progress in reducing CO2 emissions per real GDP from 1970 to around 1990. However, the pace of progress slowed in the 1990s, and since the 2000s, Japan has been overtaken by European countries, and is now at risk of being overtaken in reduction by the U.S., which has previously had the higher ratio (Figure 3(1))[6,7].

Here we will look at the figures for the energy intensity and the CO2 emission intensity separately. First, the energy intensity improved until around 1990 against the backdrop of public and private sector energy

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[5] This approach of assessing changes in CO2 emissions by decomposing them into energy-saving and energy source decarbonization factors (Kaya [1990]) has been used internationally (e.g. IPCC [2000, 2007] and IEA [2021a]).

[6] See Appendix 2 for trends in CO2 emissions in Japan during COVID-19 pandemic.

[7] France's large reductions in CO2 emissions per real GDP, and especially in CO2 emission intensity, over the 1980s were due to an increase in the share of nuclear power generation.

conservation efforts in the wake of the two oil shocks of 1973 and 1979[8]. After that, improvement slowed to a halt in the mid-2000s due to a pause in such efforts and the curbing of capital investment following the collapse of the bubble economy, allowing European countries to pursue[9]. However, since the mid-2000s, energy intensity has once again begun to improve and is not currently significantly different from that of European countries (Figure 3(2)).

CO2 emission intensity improved around 1990, but, in the same way as with energy intensity, it then stagnated in the mid-2000s. After the Great East Japan Earthquake in 2011, the CO2 emission intensity rose drastically, mainly due to the shutdown of nuclear power plants and the resulting increase in thermal power generation, and has remained high in comparison to the United States and European countries (Figure 3(3)).

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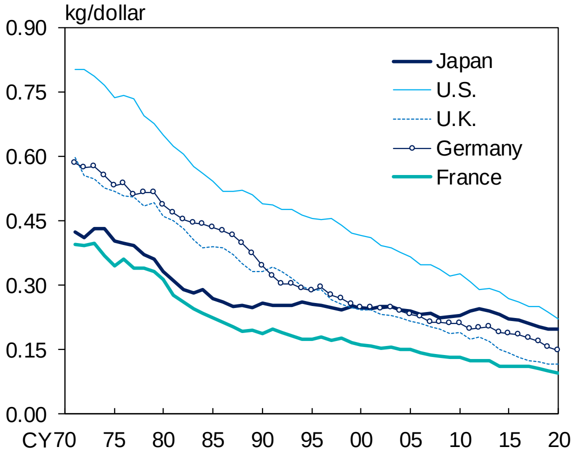
[8] For example, in 1979, an Act on the rational use of energy (the so-called "Energy Saving Act") was enacted. For more information on this background, see Agency for Natural Resources and Energy [2018].

[9] In this regard, Nomura [2021] points out that the background of the progress in energy conservation through around 1990 was the indirect introduction of energy-saving technologies, with low costs, through capital investment as they were embodied in production facilities and other equipment.

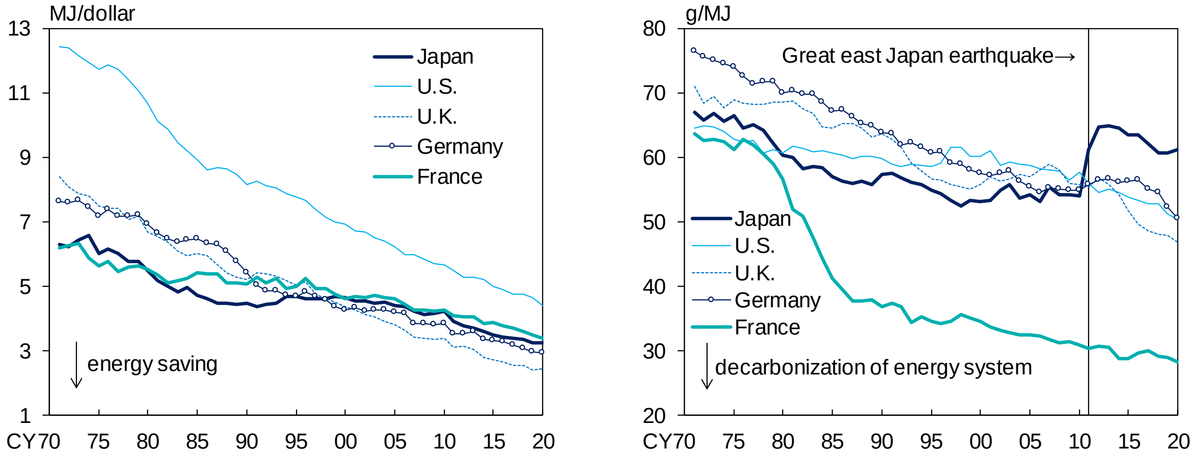
(Figure 3) Historical Decarbonization Trends

(1) CO2 emissions per real GDP



kg/dollar

	1970s	1980s	1990s	2000s	2010s	2020
Japan	0.40	0.28	0.25	0.24	0.22	0.20
United States	0.75	0.56	0.46	0.37	0.28	0.22
United Kingdom	0.53	0.40	0.30	0.22	0.15	0.12
Germany	0.55	0.43	0.29	0.23	0.19	0.15
France	0.36	0.24	0.18	0.15	0.12	0.10


(2) Energy intensity

(3) CO2 emission intensity

Note: Real GDP is PPP basis. MJ indicates megajoule, a unit of energy.
Source: IEA[2021a].

Looking at changes in energy intensity by sector (Figure 4) [10], the improvement from the 1970s to the 1990s can be explained mainly by developments in the industrial sector, especially in the manufacturing sector. This can be attributed not only to the energy savings associated with the activities of individual companies, but also to the rapid transformation of the economic structure, including the shift from a materials industry to a processing industry, as a result of the aforementioned public-private sector energy conservation efforts (Figure 5 (1)). On the other hand, since the mid-2000s, the household sector (including energy consumption from private car use) has shown a significant improvement in energy intensity (Figure 4). The

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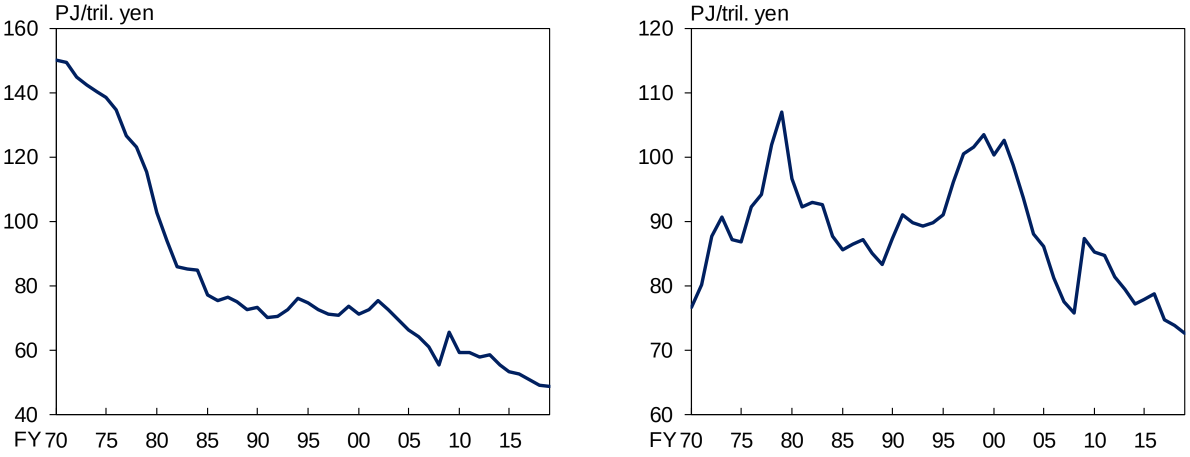
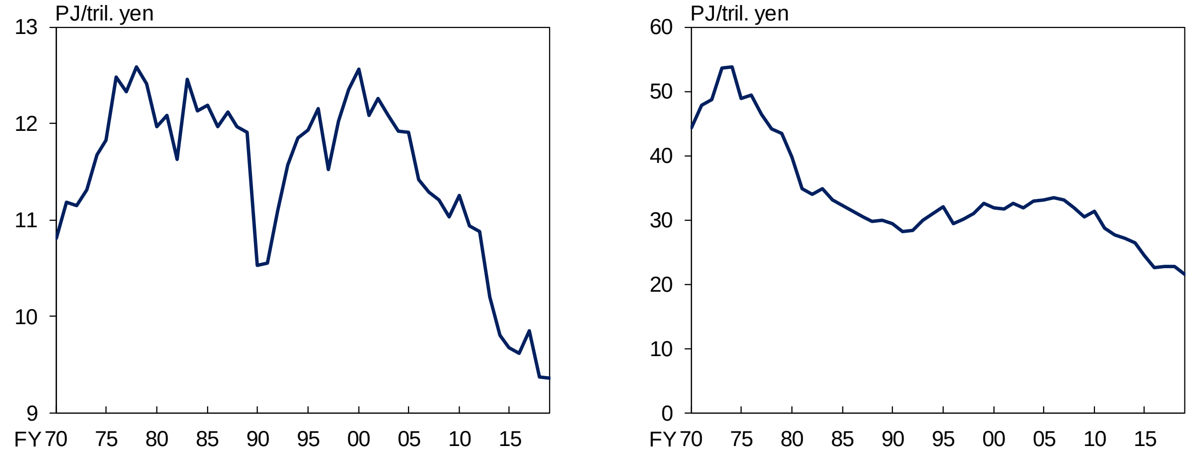
[10] The analysis for Figure 4 and 5 is from Aoki et al. [2022].

appearance and spread of durable consumer goods with excellent energy-saving performance, such as eco-cars and eco-friendly home appliances, appears to have played a major role (Figure 5(2)).

(Figure 4) Sectoral Energy Intensity



(1) Manufacturing (2) Transports

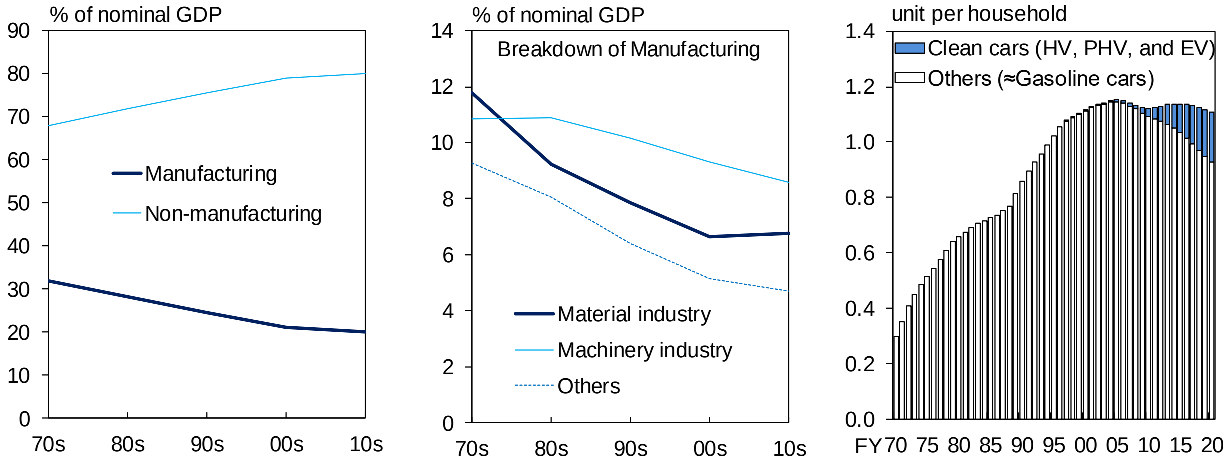


(3) Households (4) Others

Note: Transports = "Transports" - "Passenger Vehicle - Household Use", Households = "Residential" + "Passenger Vehicle - Household Use." Items in "" are from the "General Energy Statistics." Others do not include energy consumption by energy transformation and own use. PJ indicates petajoule, a unit of energy.

Source: Aoki et al.[2022].

(Figure 5) Background of Improvement in Energy Intensity



(1) Changes in Industrial Structure

(2) Growth of Clean Cars

Source: Aoki et al.[2022].

(2) Transition goals for fiscal 2030

With the current situation outlined above, we will now summarize the characteristics of Japan's CO2 emission reduction target for fiscal 2030 (-45% reduction compared to fiscal 2013).

The Sixth Strategic Energy Plan (hereafter, the SEP)[11], which was formulated to achieve the FY2030 target, assumes the growth case in the Cabinet Office's "Economic and Fiscal Projections for Medium to Long Term Analysis"[12] and aims for a 56% reduction in CO2 emission per real GDP in fiscal 2030 compared to fiscal 2013 (Figure 6(1)).

This target will be realized through (1) continued improvement of energy intensity through energy conservation (Figure 6 (2)), and (2) rapid improvement of CO2 emission intensity by restarting nuclear power plants and expanding renewable energy sources (Figure 6 (3)). Looking only at a simple comparison with past trends, the continuation of energy conservation is not an easy task, but it does not deviate significantly from the improvement trend since the mid-2000s. On the other hand, the pace of decarbonization of energy sources is unprecedented compared to the phase after the Great East Japan Earthquake and even before that, indicating that unprecedented new efforts will be required, especially in this area.

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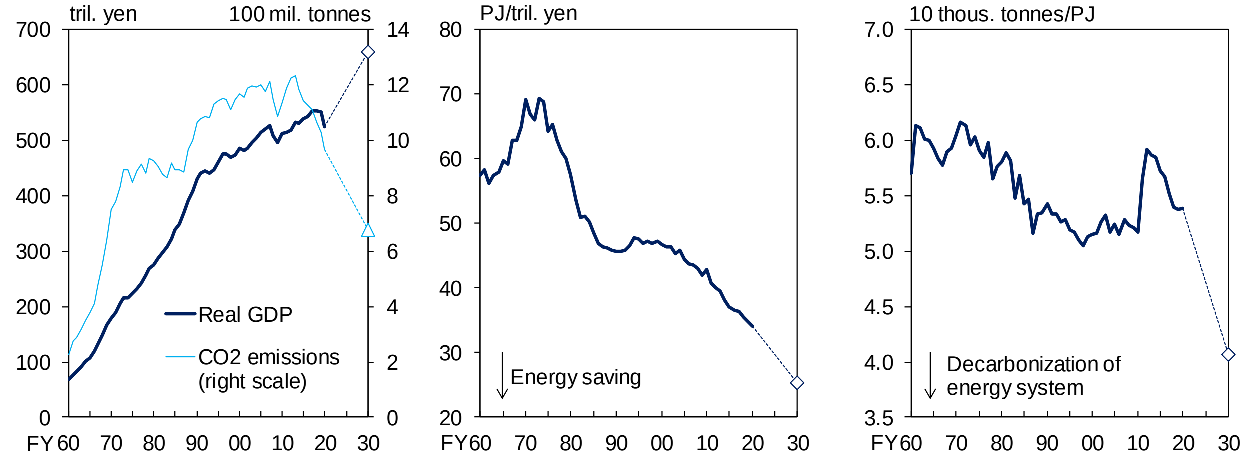
[11] Agency of Natural Resources and Energy [2021b,c].

[12] Cabinet Office [2021].

(Figure 6) CO2 Emissions Reduction Target toward FY2030

(1) Real GDP and CO2 Emissions (2) Energy Intensity (3) CO2 Emissions Intensity



Note: Figures for CO2 emissions are from energy. Figures for FY2030 are as follows:
CO2 emissions: target in Ministry of the Environment[2021b],
Real GDP: economic growth achieved case in Cabinet Office[2021],
Energy consumption: plan for primary energy supply in Agency for Natural Resources and Energy[2021b].
PJ indicates petajoule, a unit of energy.
Sources: Cabinet Office; National Institute for Environmental Studies; Agency for Natural Resources and Energy, etc.

3. Towards an orderly transition to a decarbonized society

As shown in Chapter 2, achieving a transition to a decarbonized society with stable economic growth (and plan for fiscal 2030 as a preliminary step) is no easy task. Reducing CO2 emissions is necessary, of course, to prevent physical risks from materializing. However, it is also a constraint on economic growth compared with the case without the pressure to decarbonize, and it acts as a drag on economic growth through, for example, increased costs of economic activity. To make an orderly transition to a decarbonized society, these constraints must be alleviated through appropriate economy-wide and society-wide efforts. In this chapter, we examine two channels through which the transition to a decarbonized society could constrain Japan's economy, and how these constraints could be removed.

The first channel is decarbonization through energy price change. As noted above, progress in decarbonization through fiscal 2030 is largely due to the decarbonization of energy sources, most notably the expansion of renewable energy and the use of natural gas, which has lower carbon emissions among fossil fuels. Depending on these costs, the energy prices confronting households and firms could fluctuate significantly and have a strong impact on economic activity. In particular, a continuous increase in energy prices would pose a significant risk to the economic growth of Japan, which is not a resource-rich country.

The second channel is dependent on productivity over the medium to long term in Japan's transition to a decarbonized society. If, in the process of decarbonization, less economically efficient investment increases in exchange for the benefits of CO2 emission reductions, this could lead to a decline in productivity for a country as a whole. In addition, if the transfer of capital and labor resources between industries does not proceed smoothly while the activities of industries with high CO2 emissions are sharply curtailed, this could put downward pressure on macroeconomic activity as a whole. On the other hand, in Japan, companies have so far continued to take a cautious investment stance despite their strong cash flow, and if decarbonization efforts trigger increased investment in energy conservation and other measures, this could be expected to boost productivity.

(1) Transition to a decarbonized society and energy prices

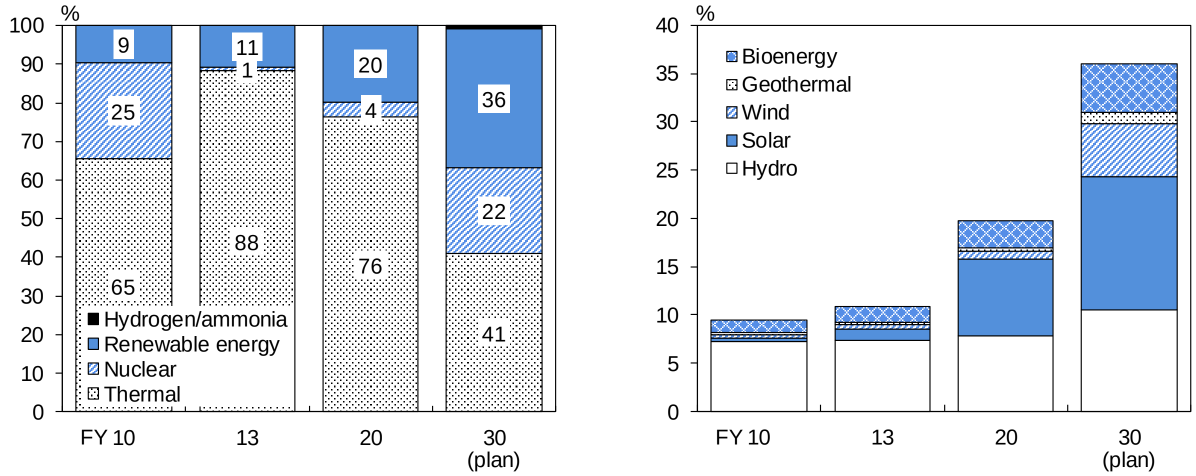
(Outlook for final energy prices under the SEP)

In considering the impact through energy price fluctuations, we begin by reviewing the power source structure in the SEP.

According to the SEP, the decarbonization of power sources by fiscal 2030 will be achieved through the expansion of renewable energy and the low-carbonization of thermal power generation (through an increase in the share of LNG (liquefied natural gas)), while nuclear power plants are being restarted. In terms of the breakdown of renewable energies, solar and wind power, as well as biomass are expected to increase, with solar power expected to be the mainstay for the foreseeable future (Figure 7 (2)). Therefore, the impact of these changes in the electricity generation mix on energy prices will depend on the cost of introducing renewable energy and the price outlook for fossil fuels, especially LNG. In this regard, the SEP assumes (1) a gradual decline in the cost of power generation as in solar power (Figure 8) and (2) that the price of fossil fuels such as LNG will remain stable in line with forecasts from international organization (IEA

[2020]) (Figure 9).

(Figure 7) Electricity Generation Mix in the SEP

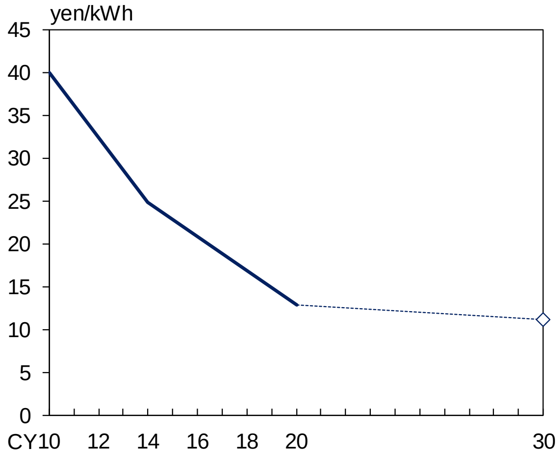


(1) Electricity Generation Mix

(2) Breakdown of Renewable Energy

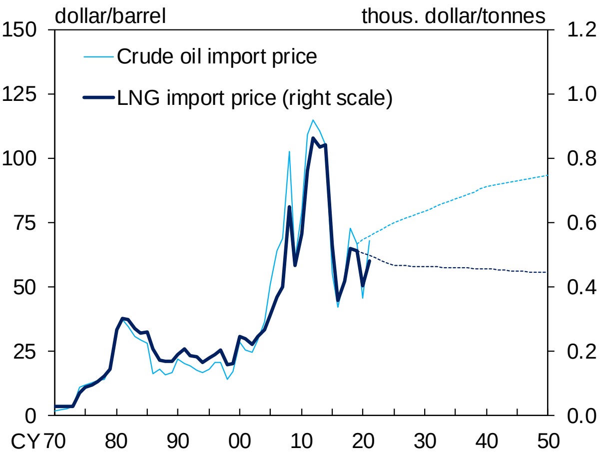
Note: Figures are share in total electricity generation. Figures for FY2030 are from the plan in Agency for Natural Resources and Energy[2021b].
Source: Agency for Natural Resources and Energy.

(Figure 8) LCOE of Solar PV



Note: The figure for FY2030 is the premise of the SEP.
Source: Agency for Natural Resources and Energy.

(Figure 9) Crude Oil/LNG Import Price



Note: Unit import value in the "Trade Statistics." Dotted line is the premise of the SEP which is based on the stated policies scenario in IEA[2020].
Sources: Agency for Natural Resources and Energy; Ministry of Finance.

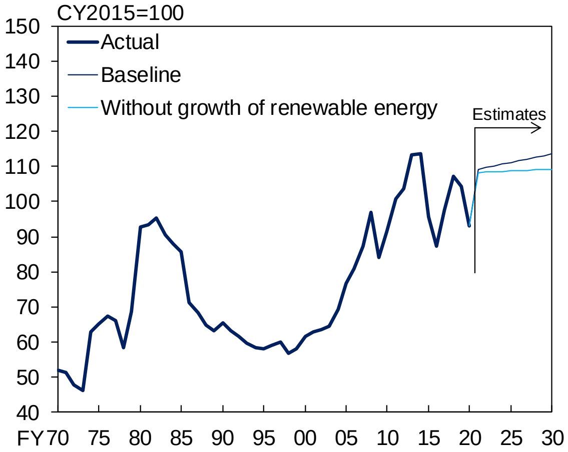
Based on various assumptions in line with the SEP (regarding consumption of various types of energy, cost of introducing renewable energy, primary energy prices, etc.), Figure 10 shows our estimates for the future final energy price that firms and households will face at the stage of energy consumption. Specifically, the price of about 20 types of energy, including oil and coal products, natural gas, city gas, and electricity were collected from the corporate goods price index and the consumer price index, and weighted by the amount of energy used in the final consumption stage (using the previous year's value) to estimate the price of energy at the final demand stage. The estimates are based on specific assumptions and should be interpreted with considerable latitude[13]. Keeping this in mind, we find that the baseline estimate will increase through fiscal 2030 by about 0.4% per year, but it is not much faster than in the case of no progress in the diffusion of renewable energy (+0.1% per year). In other words, as long as the assumptions of the SEP hold, even if the introduction of renewable energy were to proceed rapidly, the extent to which its cost would put downward pressure on the economy through higher energy prices is expected to be small.

(Figure 10) Final Energy Price (Real)

(1) Assumption

Baseline		
	Fossil fuel price	Develop as the premise of the strategic energy plan
	Renewable Energy	Increase to 36% of total electricity generation (336 bil. kWh) by FY2030
Without growth of renewable energy		
	Fossil fuel price	Develop as the premise of the strategic energy plan
	Renewable Energy	Unchange from the actual generation in FY2020 (198.3 bil. kWh) until FY2030 LNG thermal generation is assumed to increase by the volume of insufficient generation (-137.7 bil. kWh)

(2) Estimates



Note: For detail of the estimation of final energy price, see footnote 13. Figures are deflated by GDP deflator.
Sources: Agency for Natural Resources and Energy; Ministry of Internal Affairs and Communications; Cabinet Office; Bank of Japan, etc.

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[13] For the outlook of the final energy price, prices for items other than electricity are estimated based on the fuel price assumptions in the SEP. For electricity prices, as in the Agency for Natural Resources and Energy [2021b], we estimated the changes in fuel costs for thermal power generation, etc. and the purchase price of renewable energy generation by using the generation cost per kWh and fuel costs, and adding these to the actual electricity prices. For renewable energy generation, as with the Agency for Natural Resources and Energy [2021b], we assume that all renewable energy power generation will be purchased under the FIT although transition from the feed-in tariff (FIT), which purchases electricity at a fixed price, to the feed-in premium (FIP), which is a premium added to the price of electricity sold, is currently undergoing.

(Energy price uncertainty: Renewable energy installation costs and fossil fuel prices)

However, there is a great deal of uncertainty as to whether or not the various assumptions of the SEP will actually hold, and consequently there is a risk that energy prices will fluctuate significantly in both directions in the future. Although many experts have already discussed this point, this paper will focus on the following two major issues[14].

The first issue is the uncertainty surrounding the cost of introducing renewable energy. As a factor that could raise the cost of introducing renewable energy, the construction cost of solar power generation may rise as suitable sites decrease (Agency for Natural Resources and Energy [2021d]) (Figure 11). In comparison to other countries, a considerable amount of land in Japan has already been utilized for solar power generation. It has also been pointed out that the cost of ensuring a stable supply of electricity could rise rapidly with the expansion of renewable energy, where fluctuations in power generation due to weather and other factors and uneven distribution of power generation sites are inevitable (OECD/NEA [2018, 2019]).

Specifically, the Agency for Natural Resources and Energy [2021d] cites costs associated with (1) lower operating rates of thermal power generation and increased frequency of shutdowns and startups; (2) storage costs from pumped hydroelectric power; (3) costs to secure generation facilities for stable supply; (4) costs related to the development and connection of backbone transmission networks; and (5) costs for installing storage facilities. The cost estimates for (1) through (3) by the Agency for Natural Resources and Energy [2021d] and the generation cost estimates considering (1) and (2) by Ogimoto and Matsuo [2021] suggest that the introduction and diffusion of renewable energy will result in a reasonable cost for the entire power supply system (Figure 12). Regarding (4), the Organization for Cross-regional Coordination of Transmission Operators [2021] estimates that the spread of offshore wind power generation by 2040 will require several trillion yen in investments to strengthen the power grid. The expansion of these investments is expected to significantly increase

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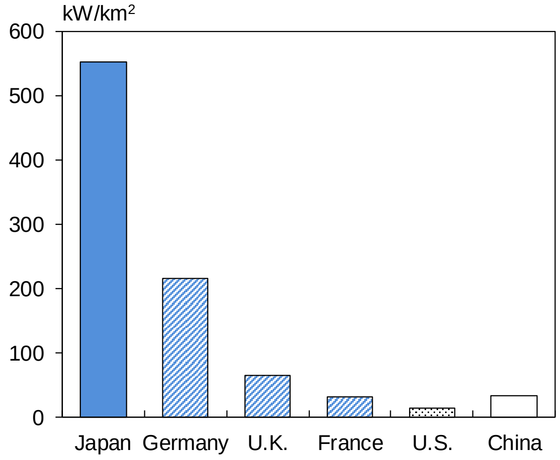
[14] In addition, the availability of nuclear power is often discussed.

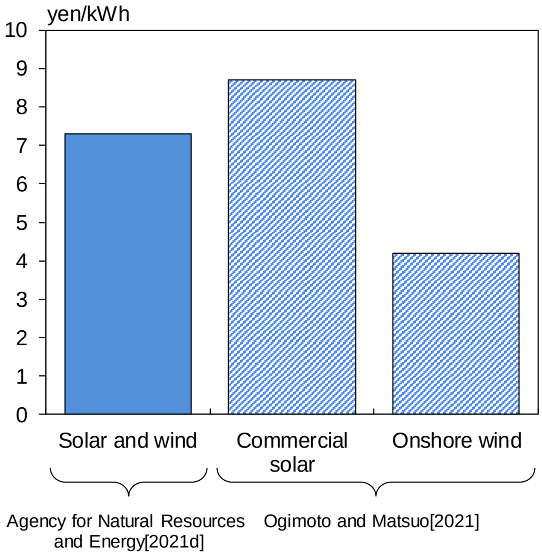
demand for resources such as copper, nickel, and lithium (IEA [2021e]), and if these prices soar, there is a risk that they will further push up the cost of renewable energy (Figure 13)[15]. On the other hand, there is a possibility that the cost of installation may fall more than expected due to progress in technological development and other factors.

(Figure 11) Solar PV Capacity per Flat Land



Note: Solar PV capacity / (land area - forest area).
Sources: Ministry of Economy, Trade and Industry; IEA[2021c].

(Figure 12) Additional Costs on Electricity System



Note: The estimate of Agency for Natural Resources and Energy[2021d] is calculated as additional costs on energy system, where the share of VRE (solar and wind) in total electricity generation is 20%, divided by the electricity generation of VRE. The estimates of Ogimoto and Matsuo[2021] are calculated as additional costs, associated with a marginal increase in commercial solar/onshore wind from the electricity generation mix in 2030, divided by the increase in electricity generation.
Sources: Agency for Natural Resources and Energy[2021d]; Ogimoto and Matsuo[2021].

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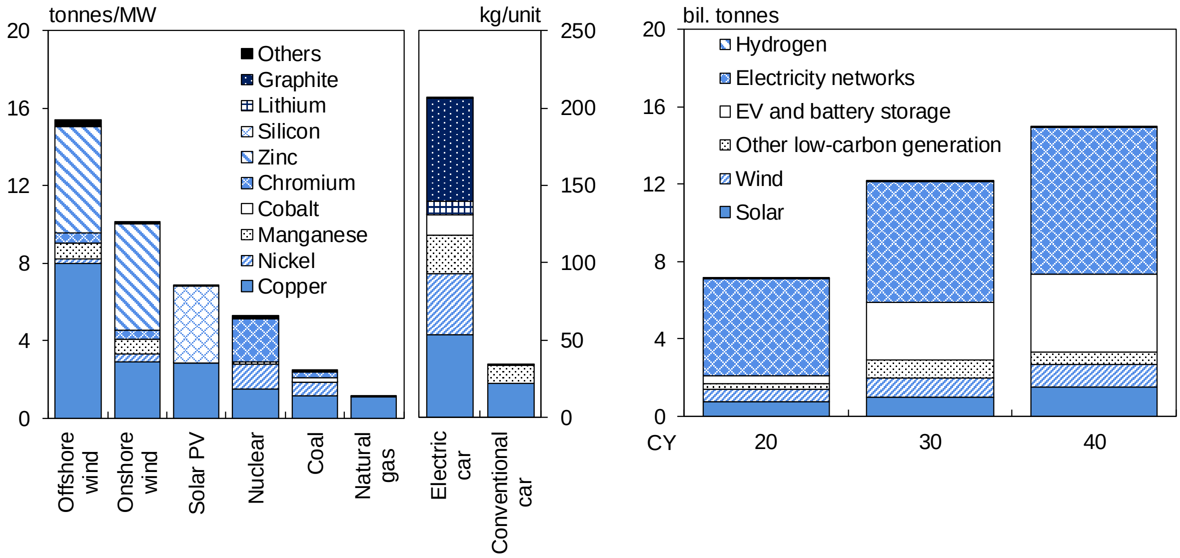
[15] In fact, it is already pointed out that the recent surge in commodity prices is putting upward pressure on the prices of renewable energy generation facilities (IEA [2021f]).

(Figure 13) Demand for Minerals with Growth of Renewable Energy, etc.


(1) Consumption of Minerals (2) Outlook for Demand

Note: Figures for 2030 and 2040 in (2) are based on the stated policies scenario.
Source: IEA[2021e].

The second major issue is the uncertainty of fossil fuel prices. Even if the decarbonization proceeds in line with the SEP through fiscal 2030, a substantial amount of fossil fuels will continue to be used for energy. In particular, the price of natural gas, which has relatively low CO2 emissions among fossil fuels, has been soaring recently due to increasing global demand and heightened geopolitical risks (Figure 14). Chief of the Commodities Unit in the IMF, Andrea Pescatori, explained that the tightening of global supply and demand for fossil fuels is due to (1) a rapid economic recovery following the COVID-19 pandemic, (2) weather factors and other demand-side developments[16], as well as (3) a slow expansion of supply (Pescatori et al. [2021]). The slow growth in supply is due to labor shortages caused by the spread of COVID-19 and uncertainty about future demand for fossil fuels due to climate change (IEA [2022]), which is restraining investment in resource development. On the other hand, the IEA [2021f] indicates that a substantial amount of new development investment will be required to meet projected natural gas demand (Figure 15). Given

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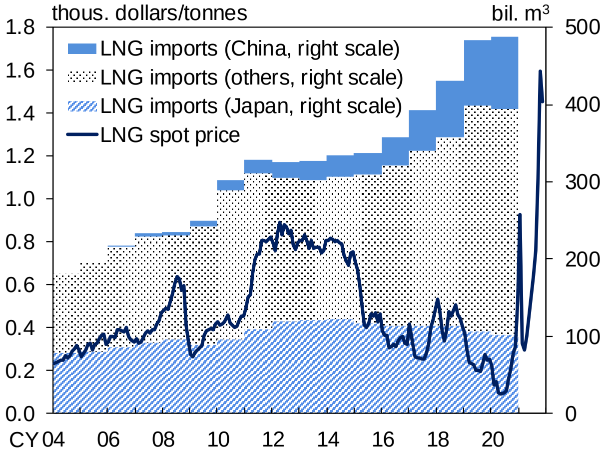
[16] In 2021, it is noted that there was an increase in demand for heating and cooling due to a severe winter and extreme heat globally, as well as an increase in demand for alternative power sources in the second half of the year due to a decline in renewable energy generation (an unexpected decrease in wind power generation) in Europe and elsewhere (IEA [2021d]).

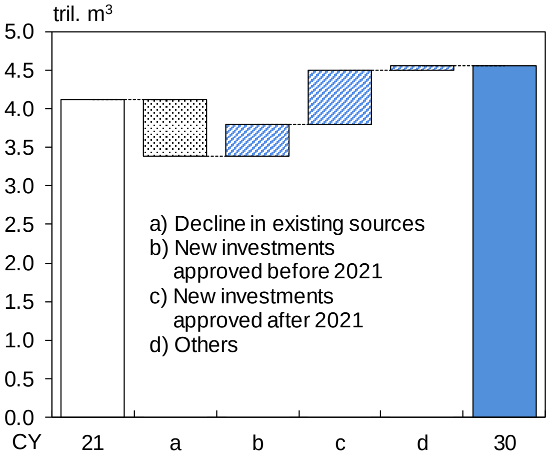
these factors, it is undeniable that there is a risk that the supply-demand balance for fossil fuels will tighten due to a lack of investment in resource development and that there will continue to be strong upward pressure on their prices. On the other hand, if global decarbonization proceeds more quickly than expected, fossil fuel prices could decline substantially.

(Figure 14) LNG Spot Price



Sources: IMF; BP[2021].

(Figure 15) Supply of Natural Gas



Source: IEA[2021f].

(Energy price changes and economic activity)

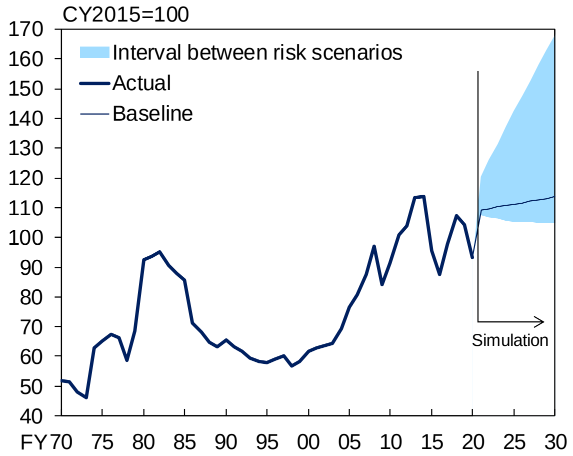
Depending on the cost of renewable energy and fossil fuel prices, the future final energy price could fluctuate significantly. In order to understand what this may look like qualitatively, simple risk simulations of future final energy price were conducted, based on a hypothetical scenario with a wide range in both directions. Specifically, we set (1) an upside risk scenario in which fossil fuel prices continue to rise at the same pace as in the 2000s and additional costs are incurred for the diffusion of renewable energy, and (2) a downside risk scenario in which both fossil fuel and renewable energy prices decline, mainly reflecting the smooth green transition of the global economy (Figure 16 (1)).

(Figure 16) Simulations of Final Energy Price (Real)

(1) Scenarios

Upward risk scenario		
	Fossil fuel price	Increase by the growth rate in 2000-2008
	Renewable Energy	Additional costs on electricity system (based on 20% VRE case in Agency for Natural Resources and Energy[2021d]) are passed through to electricity price
Downward risk scenario		
	Fossil fuel price	Moderately decrease as the sustainable development scenario in IEA[2020]
	Renewable energy	Costs of equipment and construction converge to the international prices International prices decrease in accordance with the sustainable development scenario, etc.

(2) Simulation Results



Notes: 1. For detail of the estimation of the final energy price, see footnote 13. Figures are deflated by GDP deflator.
2. "LCOE Review Sheet" in Agency for Natural Resources and Energy[2021d] is used in the simulations.
Sources: Agency for Natural Resources and Energy; Agency for Natural Resources and Energy[2021d]; Ministry of Internal Affairs and Communications; Cabinet Office; Bank of Japan, etc.

Simulation results show that in the scenario (1), in which the cost of renewable energy increases significantly and fossil fuel prices continue to rise, the final energy price will increase at a pace of about +4% per year, much faster than in the aforementioned baseline case (Figure 16 (2)). The size of this energy price increase, when converted into an annual increase in energy payments for the country as a whole, amounts to about 20 trillion yen, which is just under 4% of nominal GDP in fiscal 2019 (or 30% of current profit in the Financial Statements Statistics of Corporations by Industry, Quarterly)[17]. In addition, when the impact of continued energy price hikes on the economy is estimated using the Bank of Japan's Quarterly-Japanese Economic Model (Q-JEM),[18] which is a hybrid model developed by the Research and Statistics Department of the Bank of Japan, real GDP would be pushed down at about the mid-1% level in the 10th year (fiscal 2030) under the upside risk scenario. However, the Q-JEM is designed primarily for short- and medium-term forecasts of the economy and prices, and is in some respects insufficient to fully capture the impact of the continued rise

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[17] The estimate of the annual increase in payments for energy is obtained by multiplying the "final energy consumption in FY 2019" by the "annual increase in final energy price". According to the SEP, the amount of final energy consumption is expected to decrease through fiscal 2030 as a result of progress in energy conservation, and the amount of increase in payments for energy will decrease in the future.

[18] For detail of the Q-JEM, see Hirakata et al. [2019].

in energy prices on the economic structure. Therefore, the results of these estimates must be viewed with a wide margin of error, but it is highly likely that a sustained increase in energy prices would have a reasonably large impact on the real economy.

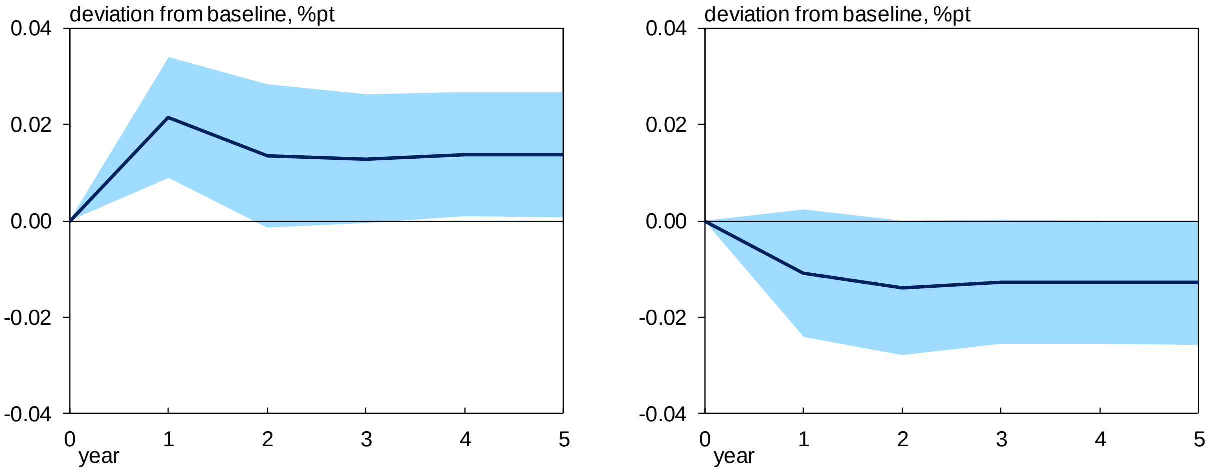
(2) Transition to a decarbonized society and productivity

(Decarbonization initiatives and productivity: Past experiences)

In the previous section, we focused on the direct impact of the transition to a decarbonized society on the Japanese economy through energy price changes. However, in the long run, significant changes in energy sources and their prices due to changing exogenous conditions can indirectly affect the rate of economic growth and productivity growth by stimulating endogenous changes in the economy, such as energy-saving investment behavior by firms and shifts in industrial structure that reflect the cost of energy inputs.

In this regard, one reference point is the improvement in energy intensity (thorough energy conservation) and reduction of CO2 emission intensity (diversification of energy sources from crude oil to LNG, etc.) since the oil crisis, as described in Chapter 2. Of course, the transition to a decarbonized society has many different characteristics from the oil crisis, such as encouraging a shift away from a wide range of fossil fuels. While these differences should be noted, it is useful to confirm the effects of past improvements in energy intensity and CO2 emission intensity on Japan's medium- to long-term growth rate and productivity. With this motivation, a VAR model was estimated using long-term time series data since 1955 to capture the impact of intensity reductions on the economic growth rate over a slightly longer time horizon. The results show that (1) improvement in the energy intensity has a significantly positive effect on the economic growth rate (potential growth rate), while (2) improvement in the CO2 emission intensity has a negative effect with statistical significance (Figure 17).

(Figure 17) Impact of Intensity Improvements on Economic Growth



(1) Improvement in Energy Intensity

(2) Improvement in CO2 Emission Intensity

Outline of VAR model

Variables: a) World real GDP (yoy % chg.), b) Japan's final energy price (real, yoy % chg.), c) Japan's potential growth (%),
d) Japan's CO2 emission intensity (yoy % chg.), e) Japan's energy intensity (yoy % chg.),
f) Japan's output gap (yoy chg.) ,

Estimation period: FY1955-2019, # of lag: 1.

Notes: 1. (1) and (2) indicate impulse responses to -1% decline shock to Japan's energy intensity and to -1% decline shock to Japan's CO2 emission intensity, respectively.
2. Shocks are identified by Cholesky decomposition with the order of variables shown in the outline of the model. Shaded area indicates 70% confidence interval calculated by bootstrapping (1,000 trials).

Sources: IMF; World Bank; Cabinet Office; Ministry of the Environment; Agency for Natural Resources and Energy; Ministry of Internal Affairs and Communications; Bank of Japan, etc.

The above estimates can be interpreted as a simple aggregation of the impact of the movement toward energy conservation and decarbonization over the past several decades on the long-term growth rate of the Japanese economy. However, the VAR model is not well suited to reflect changes in economic structure that occur over a long period of time, so one must be cautious in evaluating the quantitative results and identifying causal relationships[19].

Keeping the above points in mind, the estimation results imply that first, improvement in energy intensity leading to improvement in the economic growth rate may reflect the fact that many of the investments made in the past for energy conservation purposes also led to improvement in economic

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[19] In this paper, Cholesky decomposition was used to identify shocks in energy intensity and CO2 emission intensity, but since the model has a simple variable structure due to data constraints, etc., the accuracy of shock identification should also be noted.

efficiency. This is consistent with the "Porter hypothesis" that "well-designed environmental regulations would promote technological innovation and increase productivity" (Porter [1991])[20]. In addition, international organizations emphasize the positive economic benefits of increased investment in addressing climate change (IMF [2020], IEA [2021b], European Commission [2020]).

However, it is important to note that energy-saving investment did not always clearly increase during periods of rising energy prices, nor did increased energy-saving investment always lead to improvements in macroeconomic productivity and growth rates in the past. Fukunaga and Osada [2009] found that (1) Japan experienced "energy-saving" technological innovation after the oil shock, which also led to a boost in productivity (TFP growth rate), but (2) energy-saving technological innovations did not occur during the phase of rising energy prices in the 2000s (up to 2008) (Figure 18). In the case of (1), the impact of energy-saving technological innovations that led to improvements in energy intensity did not clearly increase until the 1980s, especially in the latter half of that decade, about 5 to 10 years after the 1970s, when crude oil prices soared. In this regard, Nomura [2021] points out that one of the reasons for the progress in energy conservation and productivity growth in energy-intensive industries such as chemicals and steel after the oil shock was the existence of low-cost energy-saving technologies at the time, but he also argues that such cases are rather exceptional events and that the sustained improvement in energy productivity in the postwar Japanese economy is a result of the development of specific industries. He emphasizes that the sustained improvement in energy productivity in the postwar Japanese economy is the result of increased efficiency in the economy as a whole (higher TFP growth rate), not investments in energy conservation in specific industries[21].

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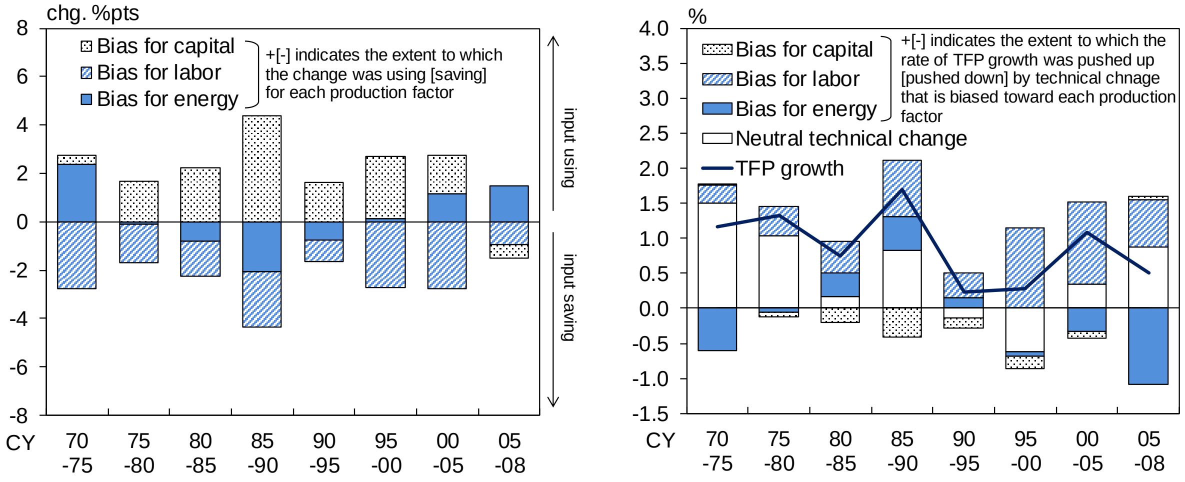
[20] However, there is currently no consensus on the relationship between environmental regulations and productivity, and further research is needed. Ambec et al. [2013] present a detailed survey of empirical analyses on the Porter hypothesis. They show that the "weak Porter hypothesis" where environmental regulations increase innovation investment, such as R&D in related fields, is generally supported, but there are both positive and negative results on the impact on productivity.

[21] Nomura also notes that in Italy in the early 2010s, the expansion of renewable energy, combined with soaring natural gas prices, pushed down the TFP growth rate due to inefficient resource allocation under rapidly rising electricity prices (Nomura

Second, the fact that reductions in CO2 emission intensity have had a negative impact on productivity, at least in the past, is a result of past CO2 emission reduction investments being characterized as costs paid to comply with regulations and diversify energy sources, and the expansion of such investments with insufficient economic efficiency may have had a negative impact on productivity and growth rate in the long run. In this regard, it has been pointed out that, at present, many of the investments associated with the decarbonization of power sources have low productivity (Nomura [2021]). Similarly, in order to avoid negative impact on productivity from decarbonization efforts, it will be important to steadily lower the cost of introducing renewable energies and, through technological development and other measures, to reduce costs when changing energy sources in the materials industry, etc., as discussed below. In addition, if such decarbonization-related technological progress leads to prospecting for global markets such as one in emerging economies where efforts are relatively lagging, or to a higher reputation among consumers who are becoming more environmentally conscious, it could positively affect productivity through higher value-added products and services.

(Figure 18) Energy-Saving Technical Change

(1) Characteristics of Technical Change (2) TFP Growth



Source: Fukunaga and Osada[2009].

[2015]).

(3) Efforts in business sector

Based on the above discussion, we summarize some key points regarding the efforts of major Japanese firms in the transition to a decarbonized society.

First, a look at the industries with relatively high CO2 emissions (before electricity and heat allocation)[22] shows that the following three sectors account for about 80% of the total: (1) electricity; (2) materials ("iron and steel", "ceramic, stone and clay products", and "chemical and oil/coal products"); and (3) transportation ("passenger and cargo transports" which use automobiles, steel ships, and other transportation equipment)[23], reflecting the industry and product characteristics (Figure 19(1)). Furthermore, looking at the cumulative distribution of CO2 emissions by company, the top few dozen companies account for more than 80% of total emissions out of approximately 600 companies in the aggregate (Figure 19(2)). Needless to say, decarbonization is a challenge that needs to be realized by society as a whole, including various companies and their consumers, but as a reduction in CO2 emissions proceeds globally, these specific industries and their major companies are more likely to be affected. In this sense, the transition to a decarbonized society is characterized not only by "macro shocks" (such as the aforementioned energy price fluctuations) but also by "sectoral shocks."

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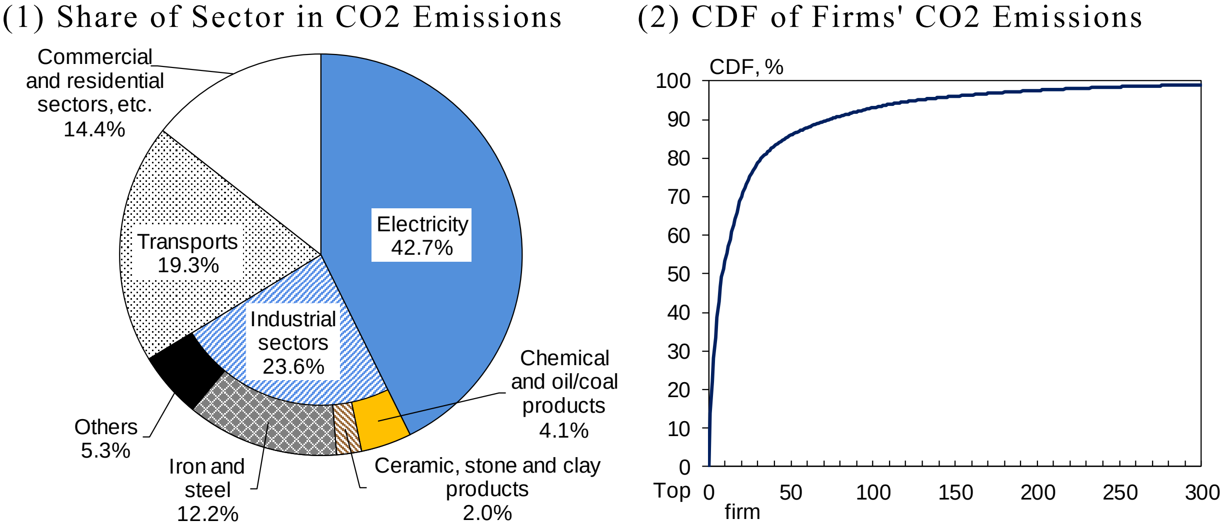
[22] A base in which emissions associated with the production of electricity or heat are calculated as emissions from the producer of that electricity or heat.

[23] Passenger transport includes the use of private vehicles by households.

(Figure 19) CO2 Emissions by Sector, by Firm


(1) Share of Sector in CO2 Emissions

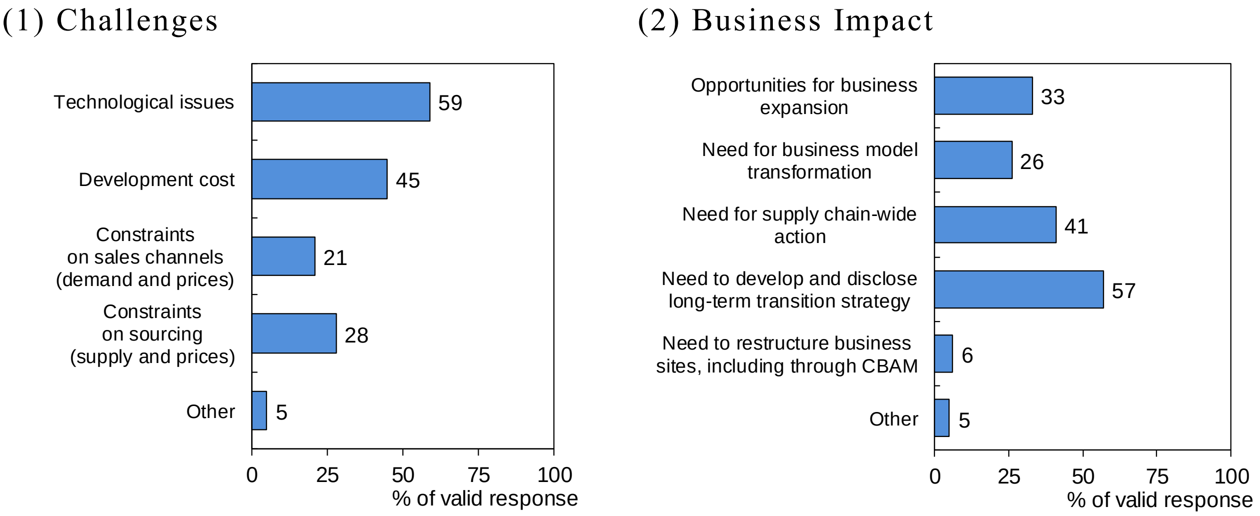
(2) CDF of Firms' CO2 Emissions

Notes: 1. CO2 emissions from electricity and heat production are allocated to those of producers of electricity and heat. Figures are as of FY2019.
2. Figures in (2) are based on the "CSR Company Hand Book (Environment)." Around 600 firms (including electric power firms) were collected.

Sources: National Institute for Environmental Studies; Agency for Natural Resources and Energy; Toyo Keizai Inc. "CSR Company Hand Book (Environment)."

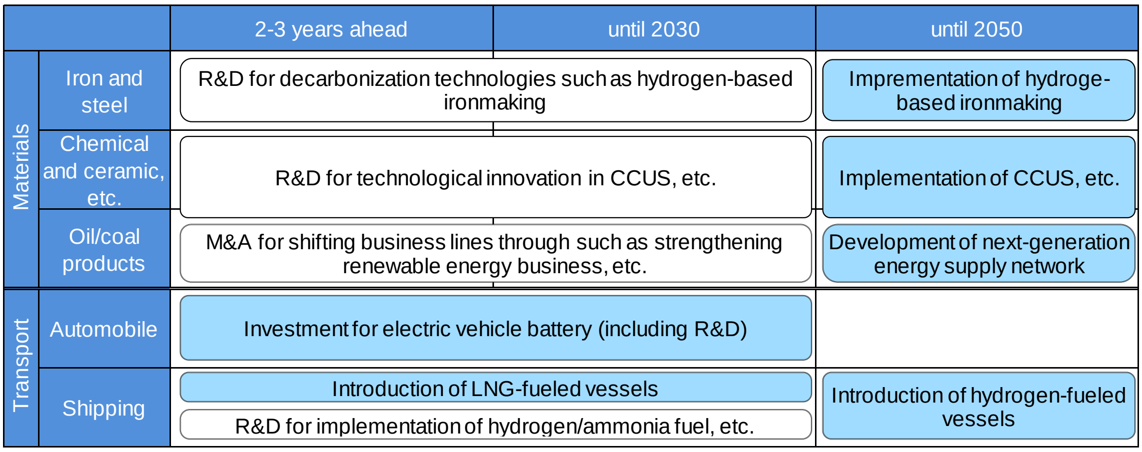
Those companies that are likely to be more affected by the transition to a decarbonized society are already adopting and accelerating their decarbonization strategies. As we have already seen, the public and private sectors are moving toward decarbonization in the electric power sector. In the materials sector, there is also a shift from oil, coal, and other energy sources to electricity, hydrogen, and other energy sources, as well as the adoption of CCUS (Carbon dioxide Capture, Utilization and Storage) technologies. In the transportation sector, the electrification of transportation is also making progress. However, several surveys indicate that the development and adoption of these technologies is encountering challenges, and there is a strong awareness of the need to formulate a long-term transition strategy (Figure 20). Looking at the business plans towards decarbonization, not a few firms have set a date far in advance when investments for decarbonization will be in full swing and when intensities will improve significantly (Figure 21).

(Figure 20) Challenges and Business Impact in Domestic and International Progress towards Carbon Neutrality



Note: Respondents choose up to two answers in (1) and up to three answers in (2). Respondents are major firms.
Source: Development Bank of Japan[2021a].

(Figure 21) Investment Plan for Decarbonization



		2-3 years ahead	until 2030	until 2050
Materials	Iron and steel	R&D for decarbonization technologies such as hydrogen-based ironmaking		Imprementation of hydroge-based ironmaking
	Chemical and ceramic, etc.	R&D for technological innovation in CCUS, etc.		Implementation of CCUS, etc.
	Oil/coal products	M&A for shifting business lines through such as strengthening renewable energy business, etc.		Development of next-generation energy supply network
Transport	Automobile	Investment for electric vehicle battery (including R&D)		
	Shipping	Introduction of LNG-fueled vessels R&D for implementation of hydrogen/ammonia fuel, etc.		Introduction of hydrogen-fueled vessels

Note: Shaded area indicates fixed asset investments and blank indicates R&D investments. CCUS (Carbon dioxide Capture, Utilization and Storage) means that the process of CO2 emissions for storage deep underground or re-use.
Sources: Firms' disclosures, etc.

Of course, it is difficult to say anything definitive at this point, as corporate efforts to decarbonize have only just begun. However, in light of these recent trends, the following three points should be considered when examining the impact of corporate initiatives on the economy as a whole.

Firstly, it is not yet clear whether corporate efforts to decarbonize will stimulate an increase in overall spending activities, including capital investment, R&D investment, and human capital investment. For a long time, the corporate sector in Japan has taken a cautious spending stance relative to its strong cash flow, resulting in a persistent excess of savings (Figure 22), unlike in Europe and the United States. In fact, in the aforementioned survey, many firms view climate change initiatives as an opportunity to expand their business (Figure 20(2)). It will also be interesting to see if the aforementioned moves by major companies to promote decarbonization initiatives spread to a wider range of companies. In this regard, partly reflecting the revision of the Corporate Governance Code, large domestic and overseas companies have strengthened the movement to promote decarbonization throughout the supply chain[24], and an increasing number of SMEs have already been asked to take decarbonization measures (Figure 23).

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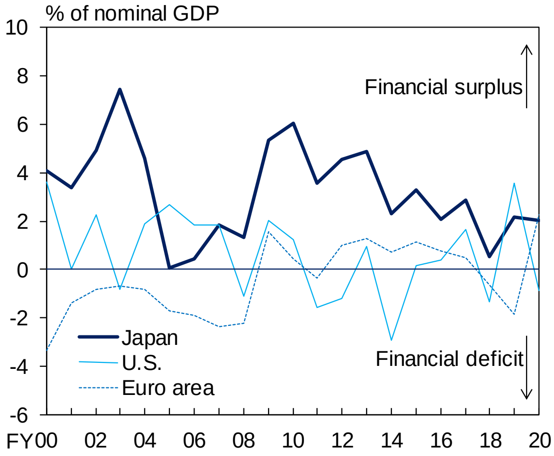
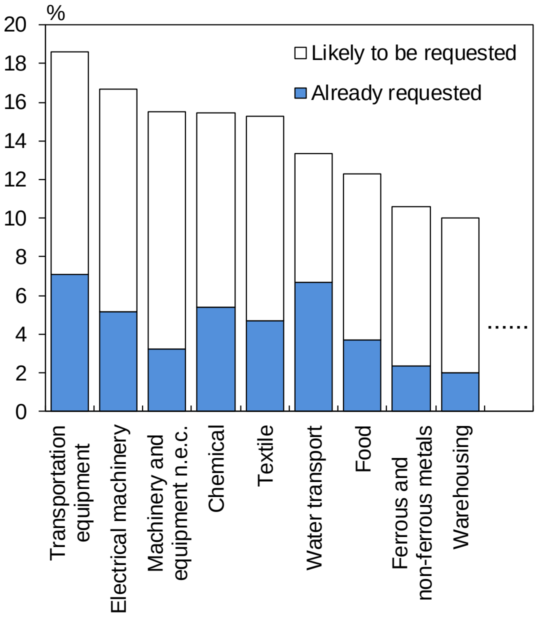
[24] For example, the Tokyo Stock Exchange revised its Corporate Governance Code in June 2021, requiring Prime-listed companies to enhance disclosure of risks related to climate change. Under these circumstances, there is a growing trend to identify GHG emissions in the supply chain, which is the sum of (1) direct GHG emissions by the business itself through fuel combustion and industrial processes (Scope 1); (2) indirect emissions from the use of electricity, heat, and steam supplied by other companies (Scope 2); and (3) emissions by other companies related to the business's activities (Scope 3). In addition, some overseas IT-related companies have set a goal of decarbonizing their entire supply chains at an early stage, and the impact of this has been seen in Japanese manufacturers of electronic components and other products.

(Figure 22) Investment Saving Balance of Corporate Sector



Note: Figures are financial surplus/deficit in the flow of funds. Figures for Japan and the U.S. are of private non-financial corporations and those for euro area are of non-financial corporations.
Sources: ECB; FRB; Bank of Japan, etc.

(Figure 23) Decarbonization Request through Supply Chains



Note: Respondents choose multiple answers to the question "Do your clients request you decarbonize?" Respondents are small and medium-sized firms.
Source: Shoko Chukin Bank [2021].

Secondly, the timing of when firms' efforts will translate into CO2 emission reductions and an increase in productivity will also have an effect. Based on the current position of firms, it will take some time for their efforts to materialize in this respect. It is said that decarbonization will require extremely innovative technologies that do not exist at this time, and thus will require more persistent efforts over a longer period of time than during the oil shock (Japan Iron and Steel Federation [2021], Petroleum Association of Japan [2021], Federation of Electric Power Companies of Japan [2021]). If a drastic reduction of CO2 emissions is forced before technological solutions can be found, there is a risk that industries with high CO2 emissions will be forced to drastically downsize[25].

In terms of technological development Japan is not lagging behind other countries in its efforts toward a decarbonized society. For example, there are many Japanese firms with advanced decarbonization-related technologies

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[25] In this regard, the Development Bank of Japan [2022] also presents similar points about the timing and cost of implementing decarbonization-related technologies and the changes in industrial structure during the transition process, as voiced by a representative Japanese company.

(Figure 24)[26]. Many firms in material industries, which are asked to take drastic decarbonization measures, have traditionally excelled in energy efficiency and other areas (Figure 25). If these firms can progress their decarbonization measures in advance of their overseas counterparts, they could increase their global presence and capture a new share in the global market, including in emerging economies. In light of these considerations, it is likely that the transition to a decarbonized society will lead to higher productivity and economic growth in the somewhat longer term.

The third point is how quickly and efficiently capital and labor can be reallocated to smoothly absorb the adjustment pressure generated in industries that will suffer relatively large impacts from the decarbonization trend in the economy as a whole during the phase of major changes in the industrial structure, as mentioned above. In this regard, the inefficiency of resource allocation due to the low liquidity in the labor market and the slow turnover of the corporate sector in Japan has been repeatedly highlighted as problematic (Nakakuki, Otani, and Shiratsuka [2004]; Fukao and Kim [2009]). For example, with regard to Japan's labor market (in the full-time employment), the practice of long-term (lifelong) employment with a single firm remains deeply rooted, and liquidity is poor, especially among middle-aged and older workers (Ozaki and Genda [2020], Yagi et al. [2022])[27]. It has also been pointed out over the years that in comparison with the U.S., fewer Japanese firms exit from the market; low-productivity firms tend to stay in the market; and capital and labor are easily fixed (Caballero et al. [2008], Nakamura et al. [2019]) (Figure 26)[28].

From this perspective, in order for Japan as a whole to make a smooth transition to a decarbonized society, it is also extremely important to reexamine the old (but new) challenges facing the economy, namely, its "sluggish response to structural change."[29]

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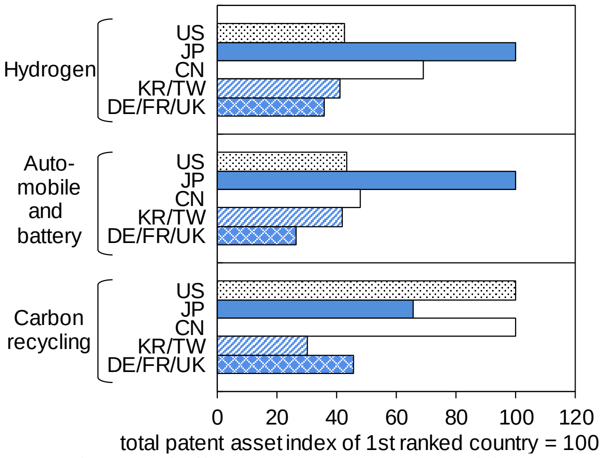
[26] For details, see Agency for Natural Resources and Energy [2021a].

[27] However, the relationship between labor market mobility and economic growth is not a simple positive relationship (Yamamoto and Kuroda [2016]). Yagi et al. [2022], who discussed recent productivity trends in Japan, point out the importance of labor market mobility accompanied by appropriate resource redistribution and human capital accumulation, and explains the role of recurrent education in this regard.

[28] For a detailed discussion of recent trends in turnover of Japanese firms and its implications for the productivity of the Japanese economy, see Yagi et al. [2022].

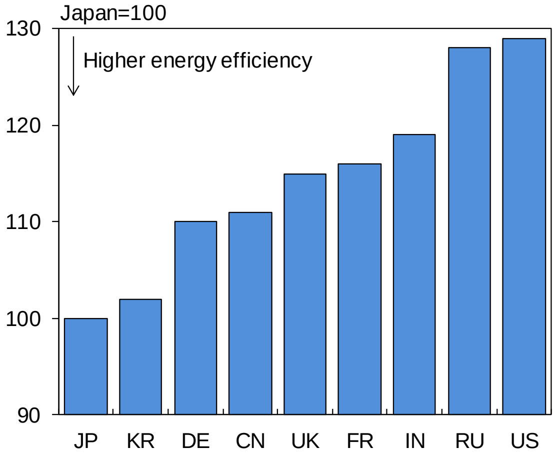
[29] In the conference "Japan's Economy During and After COVID-19 Pandemic" co-

(Figure 24) Competitiveness in Intellectual Property of Decarbonizing Technologies



Note: Figures indicate country's competitiveness of intellectual property. Those are estimated from the number of citation and views, exclusive power, and the duration, etc. of patents which are filed in Japan, the United States, China, Korea, Taiwan, the United Kingdom, Germany, and France during 2010-2019.
Source: Agency for Natural Resources and Energy [2021a].

(Figure 25) Energy Intensity of Ironmaking



Note: Figures are primary energy consumption per unit production of converter steel in 2019.
Source: Research Institute of Innovative Technology for the Earth.

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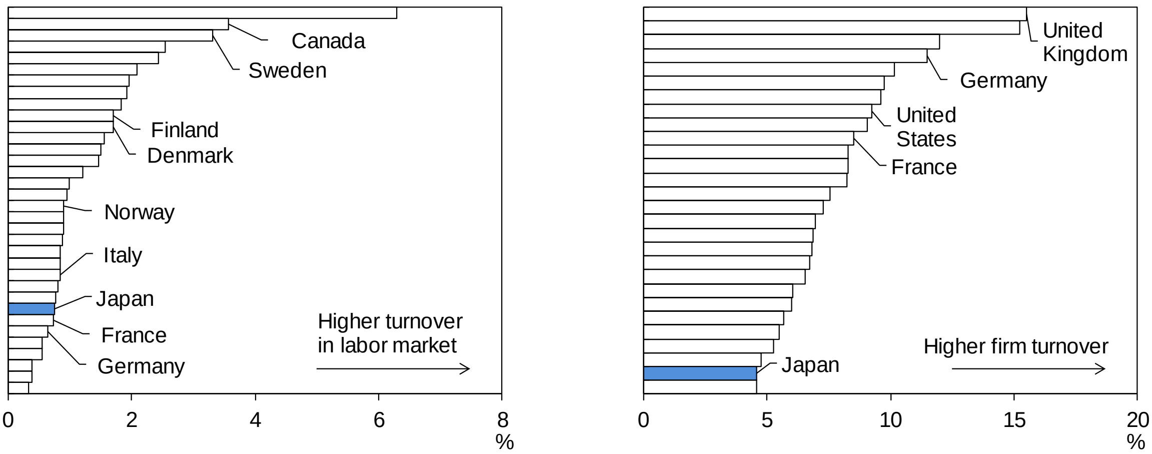
hosted by the University of Tokyo's Center for Advanced Research in Finance and the Bank of Japan's Research and Statistics Department in November 2021, the need for society as a whole to respond to changes in the rapid progress of digitization and the increasing need to address climate change issues was noted in order to increase growth potential in the post-COVID-19 (Bank of Japan Research and Statistics Department [2022]).

(Figure 26) Labor and Firm Turnover

(1) Turnover in Labor Market (2) Rate of Business Openings



Note: Figures are calculated for OECD member countries by dividing the sum of inflow and outflow of short-term unemployment (less than 1 month) by working age population in 2019.
Source: OECD.

Note: Figures are calculated for OECD member countries by dividing the number of newly registered firms by the number of registered firms in 2019. Figures for Japan are based on Ministry of Justice "Statistics on Registration" and National Tax Agency "Sampling Survey on Corporations", those for the U.S. are based on U.S. Census Bureau "The Business Dynamics Statistics", and those for the rest countries are based on World Bank "Entrepreneurship Database."
Sources: World Bank; U.S. Census Bureau; National Tax Agency; Ministry of Justice.

4. Concluding remarks

This paper presents the main challenges facing Japan's economy in the process of transitioning to a decarbonized society. It presents the facts on energy conservation in the economy and decarbonization of energy sources, a hypothetical scenario analysis on energy prices, and industry initiatives.

Japan's GHG reduction target for fiscal 2030 is based on the assumption that, in addition to steadily sustaining energy conservation, the decarbonization of energy sources, particularly power sources, will proceed at a rapid pace, which will not be easy to achieve. In particular, the costs of renewable energy deployment and the procurement costs of existing fossil fuels could have a significant impact on economic growth in the transition period. In order to ensure that the transition proceeds in an orderly manner with stable economic growth, it will be necessary to link positive corporate initiatives and investment with a rise in overall economic productivity and economic growth through the development of new markets and smooth intersectoral resource transfers. Since such efforts to promote decarbonization are likely to take considerable time, public sector is required to provide long-term support for the positive moves being made by businesses and others.

Finally, we would like to touch briefly on the impact of climate change on prices, which was not covered in detail this paper. As NGFS [2020a] and others have pointed out, climate change will affect prices through various transmission channels in terms of both physical and transitional risks. In terms of physical risks, it is possible to point out the increase in food prices and the expansion of volatility due to an increase in extreme weather events. In terms of transition risks, for example, suppliers' investment restraint and projected trends of increased decarbonization-related demand could potentially lead to soaring prices of fossil fuels and some minerals (so-called "greenflation"), which could exert stronger cost-push pressure on general prices. The introduction of carbon pricing could also act to push prices upward, depending on the design of the system and the use of tax revenues derived from it[30]. On the other hand, if economic activities are significantly constrained as a result of climate change measures and associated cost increases, there may be downward pressure on general prices mainly through the worsening of output gap. Furthermore, there is a great deal of uncertainty regarding the impact of price fluctuations via the various channels described above on people's inflation expectations. The impact of the above on prices as a whole has not yet been fully researched, even overseas, and remains an outstanding task of this paper.

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[30] Carbon pricing takes various forms, including carbon taxes, emissions trading, and credit trading, and has already been introduced in Japan in the form of the Tax for Climate Change Mitigation and credit scheme. For more detailed discussions on the use of carbon pricing, see Ministry of the Environment [2021a], and for international trends, see Ministry of the Environment [2021d] and OECD [2021a,b].

Appendix 1: Climate-related physical risk in Japan

As climate change progresses, an increase in temperatures and extreme climatic phenomena has been observed in Japan, as in other countries. In terms of temperature, the number of "extremely hot days" with daily maximum temperatures exceeding 35°C is on the increase trend, and in terms of precipitation, record-breaking heavy rains and typhoons such as the torrential rains in western Japan in 2018 and Typhoon No. 19 in 2019 (Hagibis), and an increase in the frequency of "heavy rain of short duration" with hourly rainfall of 50 mm or more.

The direct economic impacts of such climate change, i.e. physical risks, can be classified into "acute physical risks," in which extreme weather events and other events affect the economy in the short term, and "chronic physical risks," which are associated with a sustained increase in temperature.

First, in terms of acute physical risk, in Japan—because flooding accounts for a high percentage of natural disasters to begin with—attention is often focused on the increased risk of flooding due to increased precipitation. It has been pointed out that the impact of flood damage on the economy is that it puts downward pressure on production activities and profits through damage to corporate facilities, and also depresses overall economic productivity through damage to infrastructure such as bridges and roads (Yamamoto and Naka [2021], Ashizawa et al. [2022a], and Hashimoto and Sudo [2022])[31]. In addition to this, an increase in extreme weather events, such as an increase in extremely hot days, may increase the volatility of macroeconomic variables such as consumer spending and production. We attempted a simple analysis of the impact of this climatic phenomenon on short-term fluctuations in economic activity using a VAR model (Figure A1-1). Specifically, we constructed a VAR model consisting of a "Macro Weather Index (MWI),"[32] which comprehensively represents climate phenomena for

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[31] In addition, the increased risk of flooding also affects asset prices, such as land prices (Koide et al. [2022]). For an overall review of the impact of flooding on the economy, land prices, and financial institutions, see Ashizawa et al [2022b].

[32] The MWI is an index calculated as a population-weighted average of the deviation from trend of temperature and precipitation for each prefecture. See Akutsu and Koike [2019] for details on the method of construction and an example analysis using the MWI.

Japan as a whole, and various economic indicators. Then, we estimate how much of the unanticipated changes in consumer spending, goods production, and services production could be attributed to climate phenomena such as temperature and precipitation. The estimated results suggest that the effects of climate change have intensified in recent years, particularly in consumer spending and service production, and that the increase in extreme climatic events has increased the variability of economic activity over a period of several months, which is shorter than the business cycle.

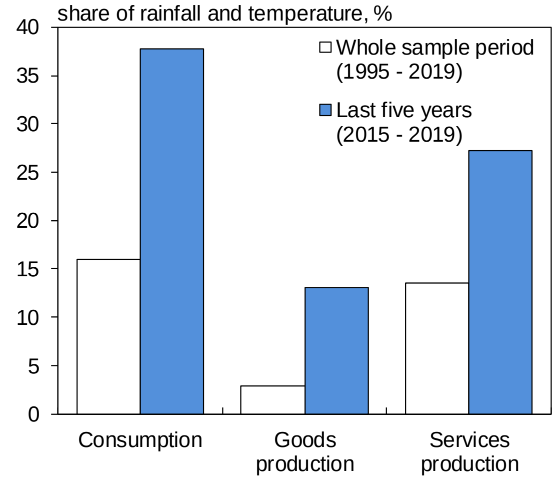
(Figure A1-1) Fluctuations of Economic Indicators and Climate Phenomena

(1) Outline of VAR Model

	Variables	Lags
Consumption	MWI, Fresh food price (mom), TOPIX (mom), Real employees' income (mom), and Synthetic consumption index (mom)	1
Goods production	MWI, World trade volume (mom), Real effective exchange rate (mom), Real domestic demand (mom), and Industrial production index (mom)	3
Services production	MWI, Real domestic demand (mom), and Indices of Tertiary Industry Activity (mom)	2

MWI: rainfall, temperature in summer (May to August), and temperature in summer (November to January).
Estimation period: January 1995 - December 2019.

(2) Variance Decomposition



Note: Figures in (2) are share of rainfall, temperature in summer, and that in winter in the variance decomposition for three months ahead. Shocks are identified by Cholesky decomposition.
Sources: Japan Meteorological Agency; Cabinet Office; Ministry of Economy, Trade and Industry; Ministry of Internal Affairs and Communications; Ministry of Health, Labour and Welfare; CPB Netherlands Bureau for Economic Policy Analysis; Japan Center for Economic Research; Bloomberg.

Second, chronic physical risks are being actively analyzed globally to determine whether a sustained increase in temperatures could lead to a decrease in agricultural output and labor productivity (Schleussner et al. [2018], Ortiz-Bobea et al. [2021], Dasgupta et al. [2021],[33] etc.). Although no consensus has yet been reached on this point, in the following, we apply the analytical methodology used in Kahn et al. [2019] at the IMF for the United States to our country using prefectural data to estimate the long-term effects of climate change on labor productivity (Figure A1-2). Using long-term prefectural panel data for Japan, we estimated an ARDL model with the real labor productivity growth rate as the dependent variable, and found that the estimated effect was statistically significantly negative with respect to

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[33] These studies are also cited in NGFS [2021].

temperature increase. This analysis suggests that in Japan, as in the U.S., rising temperatures can depress the rate of increase in labor productivity over the long run.

(Figure A1-2) A Rise in Temperature and Labor Productivity

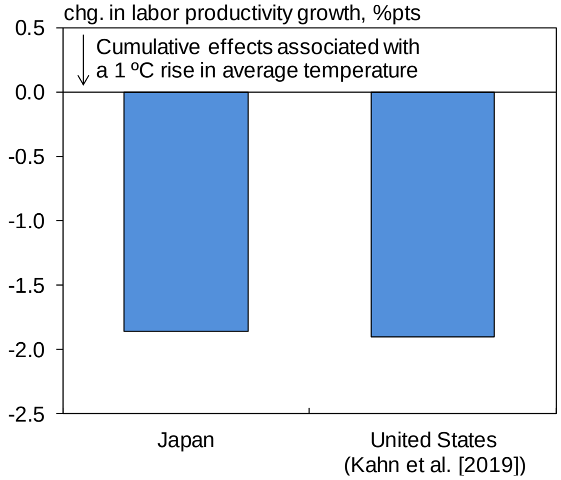
(1) Outline of Estimation

Regression model (ARDL model)

$$
\begin{aligned}
&\mathit{\Delta Real\ labor\ productivity}_{i,t} \\
&= \mathit{Constant} + \textstyle\sum_{k=1}^{5} \varphi_k \cdot \mathit{\Delta Real\ labor\ productivity}_{i,t\text{-}k} \\
&\quad + \textstyle\sum_{k=0}^{5} \beta_{1k} \cdot \Delta(\mathit{Temperature}_{i,t\text{-}k} - \overline{\mathit{Temperature}}_{i,t\text{-}k\text{-}1}) \\
&\qquad\qquad \cdot I(\mathit{Temperature}_{i,t\text{-}k} \geq \overline{\mathit{Temperature}}_{i,t\text{-}k\text{-}1}) \\
&\quad - \textstyle\sum_{k=0}^{5} \beta_{2k} \cdot \Delta(\mathit{Temperature}_{i,t\text{-}k} - \overline{\mathit{Temperature}}_{i,t\text{-}k\text{-}1}) \\
&\qquad\qquad \cdot I(\mathit{Temperature}_{i,t\text{-}k} < \overline{\mathit{Temperature}}_{i,t\text{-}k\text{-}1}) \\
&\quad + \textstyle\sum_{k=0}^{5} \beta_{3k} \cdot \Delta(\mathit{Rainfall}_{i,t\text{-}k} - \overline{\mathit{Rainfall}}_{i,t\text{-}k\text{-}1}) \\
&\qquad\qquad \cdot I(\mathit{Rainfall}_{i,t\text{-}k} \geq \overline{\mathit{Rainfall}}_{i,t\text{-}k\text{-}1}) \\
&\quad - \textstyle\sum_{k=0}^{5} \beta_{4k} \cdot \Delta(\mathit{Rainfall}_{i,t\text{-}k} - \overline{\mathit{Rainfall}}_{i,t\text{-}k\text{-}1}) \\
&\qquad\qquad \cdot I(\mathit{Rainfall}_{i,t\text{-}k} < \overline{\mathit{Rainfall}}_{i,t\text{-}k\text{-}1})
\end{aligned}
$$

i: prefecture, t: year, k: lag.
Estimation period: 1976 - 2012.

(2) Impact on Labor Productivity Growth



Notes: 1. Temperature and Rainfall are past 30-year averages.
2. Figures in (2) are calculated by $\sum_{k=0}^{5} \beta ik / (1 - \sum_{k=1}^{5} \varphi k)$, and are statistically significant at 1% level for both Japan and the United States. The estimation period in Kahn et al.[2019] is 1976-2016.
Sources: Research Institute of Economy, Trade and Industry; Japan Meteorological Agency; Kahn et al.[2019].

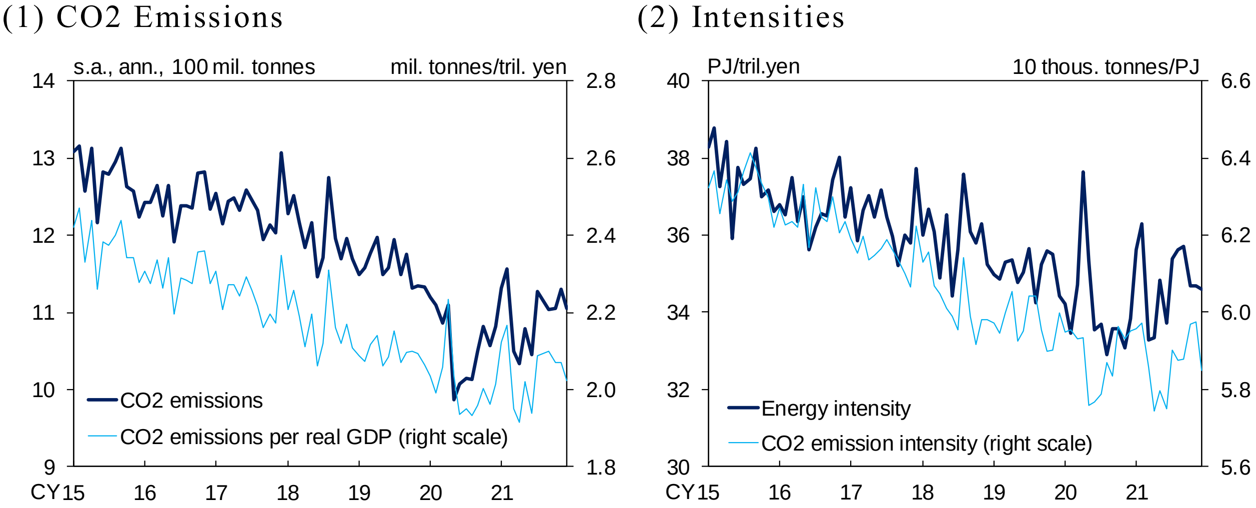
As described above, in Japan, as in other countries, it is likely that the progression of climate change is having an impact on economic activity. At this point, however, there is not yet sufficient research, and the analysis presented here is only tentative and based on rough data. As for the physical risks of climate change —as well as transition risks—there is a need for further analysis based on detailed data in the future.

Appendix 2: Development of Japan's CO2 emissions during the COVID-19 pandemic

After the COVID-19 spread in the spring of 2020, Japan's CO2 emissions have been significantly reduced in level, and the CO2 emissions for fiscal 2020 (preliminary value) decreased by 6% from the previous year (Figure 6). However, the main cause of the decrease is the decline in the level of economic activity (year on year growth rate of real GDP in fiscal 2020: -4.5%), and the pace of decline in CO2 emissions per real GDP has slowed.

We tentatively estimated monthly CO2 emission index and looked at its trends toward the end of 2021 (Figure A2-1)[34]. The index shows no significant change in the trend in 2021 from that in 2020. Looking at the CO2 emission intensity, it continues to improve gradually. On the other hand, the energy intensity has been fluctuating around the same level.

(Figure A2-1) Monthly Developments in CO2 Emissions (Estimates)



Note: Latest data is as of December 2021. For the estimation method, see footnote 34. PJ indicates petajoule, a unit of energy.

Sources: Agency for Natural Resources and Energy; Ministry of Economy, Trade and Industry; Ministry of Finance; Cabinet Office; National Institute for Environmental Studies; Japan Center for Economic Research.

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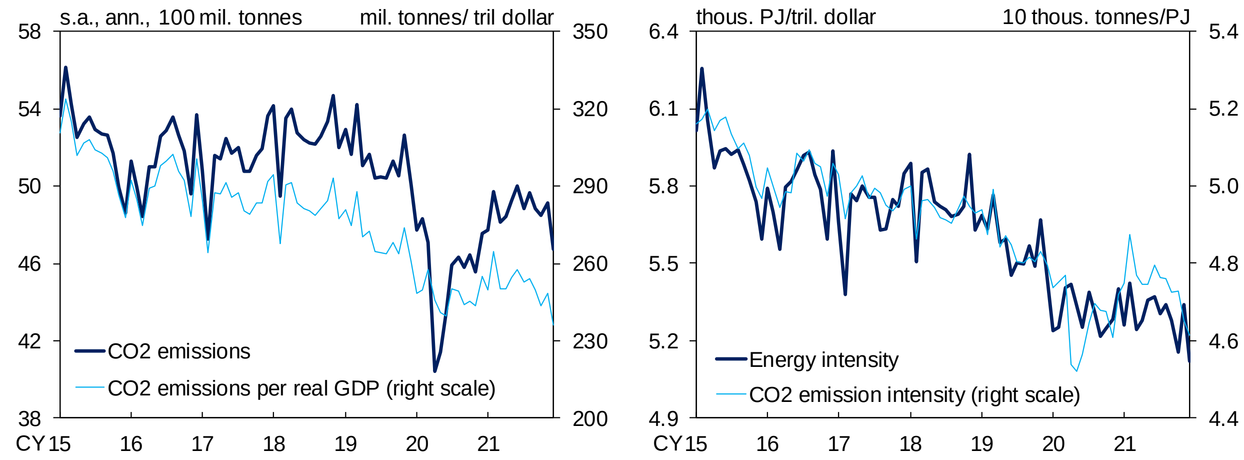
[34] The monthly CO2 emission index is estimated based on the supply-side approach. Specifically, the total domestic supply of fossil fuels and other energy sources was calculated from monthly statistics, and then multiplied by the energy conversion factor and carbon emission factor of the previous year to arrive at the estimated values. However, due to the limitations of the source data, some of the values are unchanged from the previous year, and the actual CO2 emissions (fiscal year basis) are based on the consumption side approach, so the results of the estimation should be viewed with a wide range. For more information on the cases of calculating monthly or quarterly CO2 emission data in other countries, see Andrew [2021].

This may be due to the fact that while the level of activity, especially in the face-to-face service sector, has been suppressed under the COVID-19 pandemic, production in the manufacturing sector, driven by the recovery of overseas economies and digital-related demand, has been on an upward trend. In other words, the higher weight of the manufacturing sector, which consumes relatively more energy, is thought to have contributed to the increase in energy intensity. Such a pause in the improvement of energy intensity has also been observed in the U.S. (Figure A2-2).

(Figure A2-2) Monthly Developments in CO2 Emissions (U.S.)

(1) CO2 Emissions (2) Intensities



Note: Latest data is as of December 2021. PJ indicates petajoule, a unit of energy.
Sources: EIA; Haver.

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