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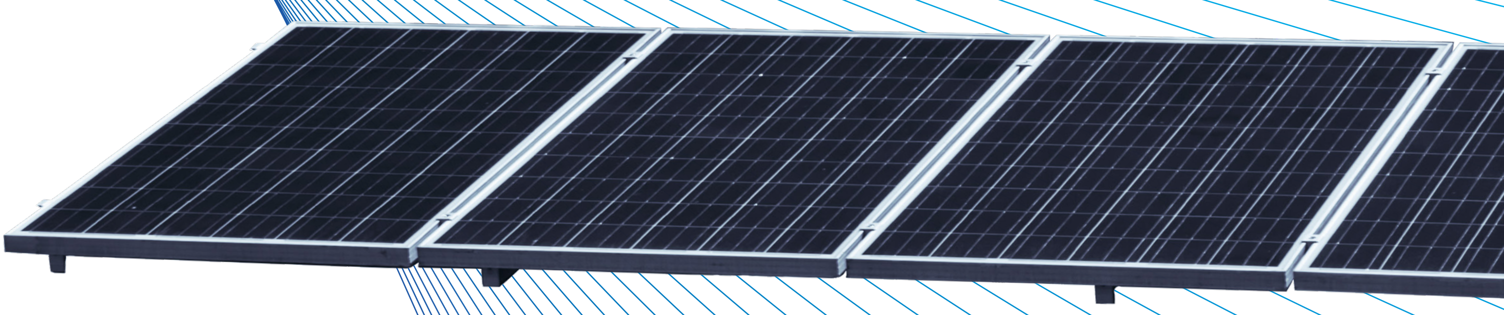
Meeting Japan’s Paris Agreement targets—more opportunity than cost

Japan can meet its Paris Agreement targets in 2030 and 2050—but it will require carefully calibrating efforts across four key sectors: power, industry, transport, and buildings.



March 2020

In brief

This report outlines how Japan can meet its emissions-reduction targets for 2030 and 2050. Our analysis identifies the most cost-effective measures to achieve Japan's commitment to reduce greenhouse gas emissions by 26 percent by 2030 and provides a pathway to achieve an 80 percent reduction by 2050. Ninety-five percent of all abatement required to meet the 2030 target can be achieved through measures that are either cost neutral or result in lifetime cost savings. This finding suggests that Japan has opportunities to not only curb emissions but also maintain competitiveness in key decarbonization technologies and stimulate economic growth.

Introduction

Due to a rapid increase in the amount of greenhouse gases (GHGs) in the Earth's atmosphere and oceans, global average temperatures have increased by more than one degree Celsius since preindustrial times. In Japan, the average temperature increased by 1.19 degrees Celsius over the past century.[1] An increase in the global average temperature leads to sea-level rise and intensifies extreme weather events that pose a severe threat to human health, agriculture, social infrastructure, and economic activities.[2] These events will only intensify as the planet continues to warm.

In the most significant initiative to fight climate change, the Paris Agreement, governments around the world committed to capping global temperature rise well below 2.0 degrees Celsius above preindustrial levels, with a stretch goal of limiting the temperature increase to just 1.5 degrees Celsius. These goals are ambitious, given that the current trajectory and rate of carbon emissions would result in a warming of 3.5 degrees Celsius by 2100.[3]

As part of this effort, Japan has committed to reducing GHG emissions by 26 percent by 2030 and 80 percent by 2050 (both compared with 2013 baseline emissions of 1,407 megatons of carbon dioxide equivalent ($MtCO_2e$)). Japan's commitment equates to a reduction of 365 $MtCO_2e$ by 2030 (down to 1,042 $MtCO_2e$ per year) and a further 760 $MtCO_2e$ reduction by 2050 (down to 282 $MtCO_2e$ per year).

1 *Climate change monitoring report 2017,* Japan Meteorological Agency, October 2018, jma.go.jp; *National plan for adaptation to the impacts of climate change,* Cabinet Decision, November 27, 2015, env.go.jp.
2 US National Climate Assessment 2018, *Volume II: Impacts, risks, and adaptations in the United States*, US Global Change Research Program, nca2018.globalchange.gov.
3 *Emissions gap report 2019*, United Nations Environment Programme, unenvironment.org.

Thanks to improvements in industrial efficiencies, reductions in industrial production, and increased adoption of renewable energy, Japan achieved a reduction of 102 $MtCO_2e$ per year compared with the 2013 baseline by 2016[4]—leaving a further reduction of 263 $MtCO_2e$ in annual emissions required by 2030.

How can Japan get there? In this report, we offer an overview of our analysis detailing the most cost-effective pathway for Japan to meet its commitments to decarbonization, the investment required to deploy the decarbonization technologies, and key enablers to get started.

We simulated the optimal (most economic) technology mix for the four key economic sectors in Japan—power, industry,[5] transport, and buildings—which together contributed 79 percent of Japan's total GHG emissions in 2016. Since most of these sectors are forecast to see increased activity from 2016 to 2030, we estimate an emissions increase of 37 $MtCO_2e$ beyond the baseline from 2016 to 2030.[6] As a result, we estimate that Japan must identify 300 $MtCO_2e$ of abatement within the four sectors to meet the 2030 target. The remaining 65 $MtCO_2e$ would come from sectors outside the scope of this analysis.[7]

The simulation optimizes technology switching on a year-to-year basis based on the current technology mix, asset lifetime, projected cost of technology, and demand projection. The simulation minimizes lifetime technology cost across all four sectors under the restriction that emissions-reduction target is met. For the power sector, we also simulated an hourly dispatch that considers the local electricity load profile, the profile of renewable resources, the minimum requirement on system reliability, and the projected demand growth of electricity from increasing electrification.

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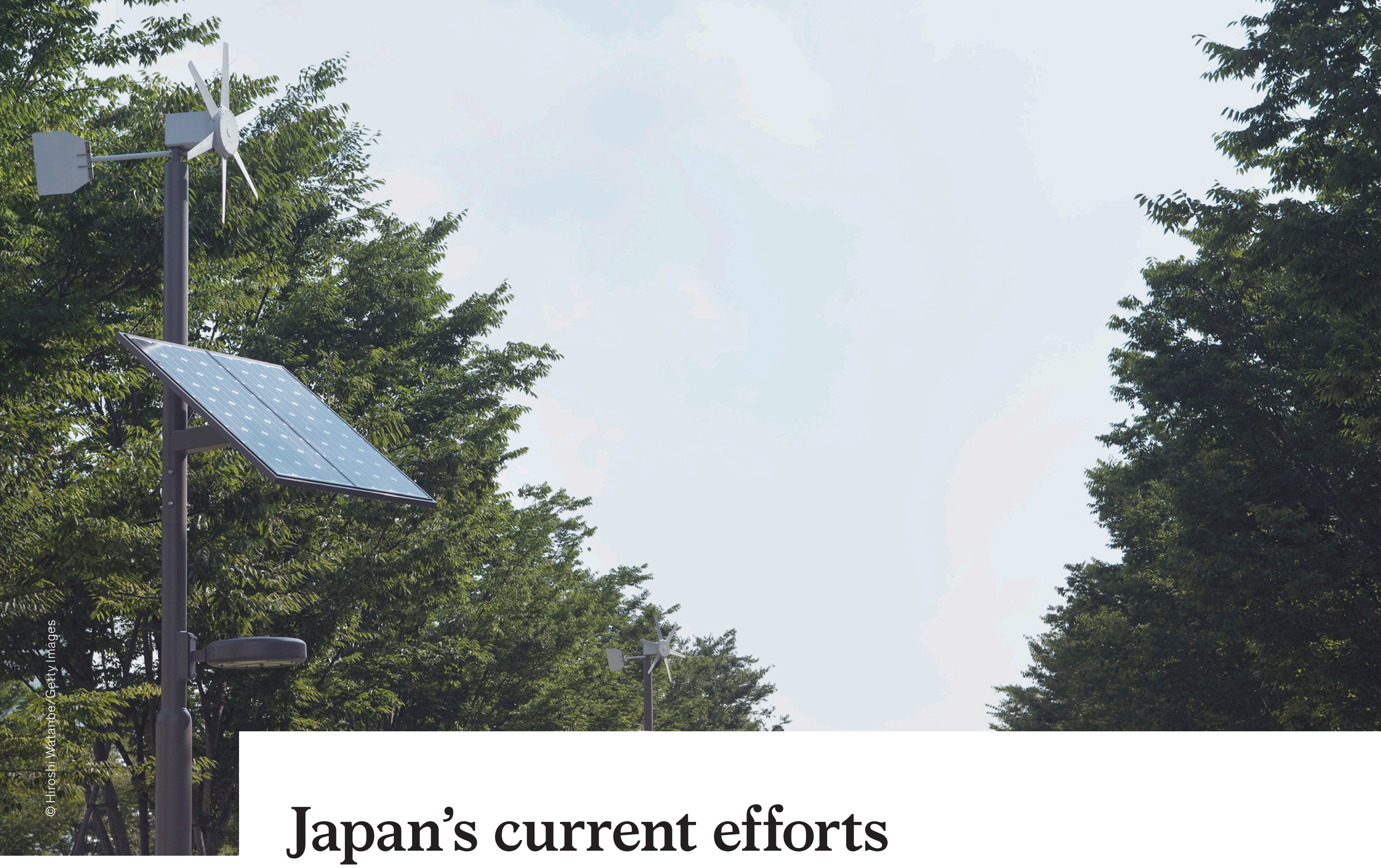
4 This analysis uses 2016 as the baseline year because it was the most recent year the National Inventory Report was published as of April 2019 when this research began. Since then, the National Inventory Report for 2017 has been published, reporting a total of 1,292 $MtCO_2e$ in 2017.

5 Industry refers to iron and steel production, cement production, refining, and pulp and paper.

6 Activity projection based on "Long-term energy supply and demand outlook," Japan Ministry of Economy, Trade and Industry, enecho.meti.go.jp. For industries with projected activity increase, emissions increase is factored into the required emissions reduction target. Emissions reduction from projected activity decrease in industry (for instance, the retirement of production capacity) is explicitly counted and discussed in the following sections.

7 These sectors include agriculture, waste, land use, land-use change, and forestry.



Japan's current efforts and challenges moving toward decarbonization

Overall, Japan's emissions have grown marginally at an average annual growth rate of 0.1 percent over the past 30 years.[8] The global economic recession resulted in a steady emissions decline from 2008 to 2011. However, emissions grew meaningfully after 2011 when the tragic accident at the Fukushima Daiichi Nuclear Power Plant prompted the closure of nuclear power plants across the country and their output was replaced by coal, natural gas, and oil generation. As a result, fossil fuel–based thermal power generation increased from 65 percent of Japan's total electricity generation mix in 2010 to 89 percent in 2012.[9] In 2016, Japan emitted 1,305 $MtCO_2e$—making it the fifth-largest emitter in the world after China, the United States, India, and Russia.[10]

By signing the Paris Agreement, Japan targeted a 26 percent reduction in GHG emissions by 2030 and an 80 percent reduction in GHG emissions by 2050 (compared with the 2013 baseline of 1,407 $MtCO_2e$). The 2030 target will require a 1.8 percent average annual reduction over the next decade; the 2050 target is more aggressive and will require a 6.3 percent reduction each year from 2030 to 2050 (Exhibit 1).

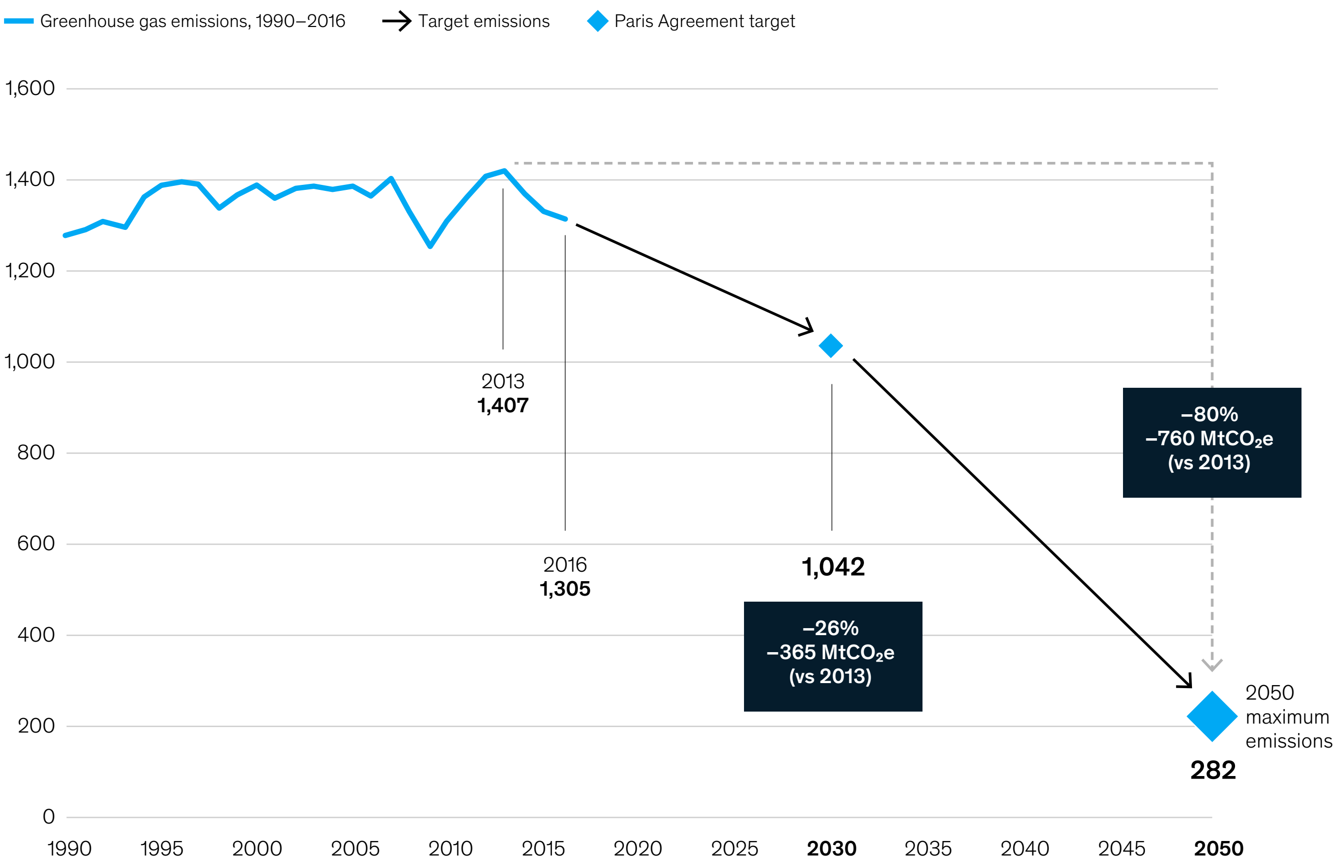
In addition to signing the Paris Agreement, the Japanese government has set out a road map for decarbonization. Most notably, the National Plan for Adaptation to the Impacts of Climate Change

[8] According to the Greenhouse Gas Inventory Office of Japan, the country emitted 1,275 $MtCO_2e$ in 1990 and 1,292 $MtCO_2e$ in 2017.
[9] METI General Energy Statistics, Agency for Natural Resources and Energy, June 27, 2019, enecho.meti.go.jp.
[10] *Fossil CO_2 & GHG emissions of all world countries, 2017*, EDGAR—Emissions Database for Global Atmospheric Research, October 30, 2017, edgar.jrc.ec.europa.eu.

Exhibit 1

As part of the Paris Agreement, Japan set a decarbonization target of –26 percent by 2030 and –80 percent by 2050 versus the 2013 baseline.

Megatons of carbon dioxide equivalent ($MtCO_2e$)



Source: UNFCCC 2018 National Inventory Report; Japan National Institute for Environmental Studies

(National Adaptation Plan) and the Long-term Energy Supply and Demand Outlook (Long-term Energy Outlook) detail measures to achieve the 2030 target. The government's Long-Term Strategy under the Paris Agreement sets the strategic direction for 2050. Private enterprises have also acknowledged their important roles in decarbonization, and many industry associations in Japan have created action plans to help Japan meet the decarbonization target for 2030.

Japanese industry can draw on past success to inform decarbonization efforts. For example, energy intensity of GDP decreased by a significant 40 percent from the 1970s to the 2010s,[11] due in large part to efficiency gains of up to 50 percent in the electricity, steel, and chemical sectors.[12] Japan will also see some natural declines in CO_2e emissions because of forecasted population decreases and related reductions in economic activity in certain sectors.

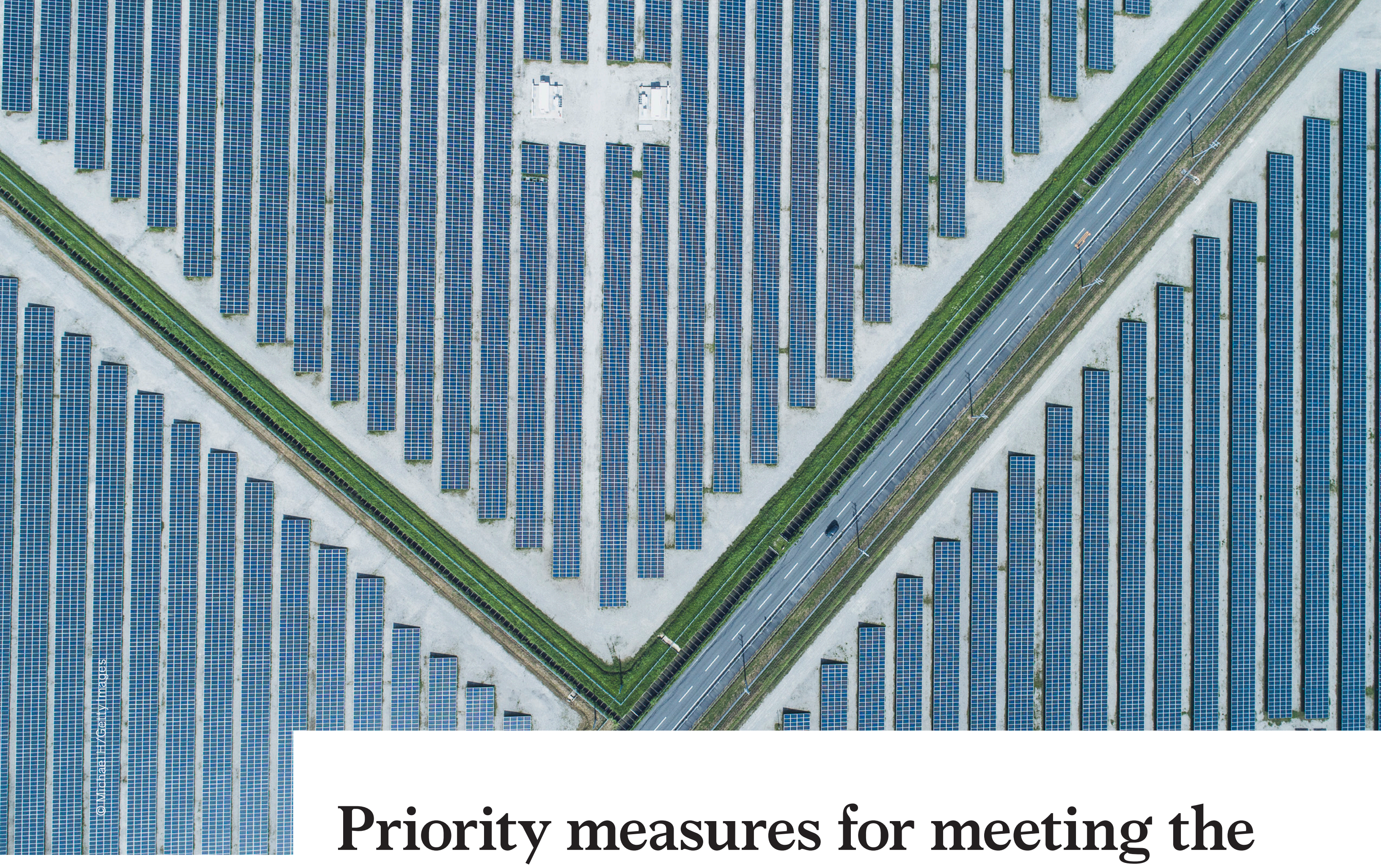
[11] DataBank, World Bank, accessed June 27, 2019, databank.worldbank.org.

Our findings suggest that 95 percent of the abatement required to meet the 2030 Paris Agreement target can be achieved through measures that are cost neutral or that result in cost savings for Japan.

However, despite these efforts, Japan's decarbonization challenge remains significant. Thirty-three percent of Japan's emissions come from "hard to abate" industrial sectors in which technology for deep decarbonization is still not mature or cost effective. The country continues to have some of the highest CO_2 intensity of energy among the countries of the Organisation for Economic Co-operation and Development (OECD).[13]

Nuclear power, which delivers the largest share of abatement under the government plan, has an uncertain future. The Japanese government's Long-term Energy Outlook calls for a 2030 electricity mix that includes 20 to 22 percent nuclear power, up from 3 percent in 2017; however, because of new safety standards that involve significant additional safety testing, earthquake resistance retrofitting, anti-terrorism measures, and low public acceptance, restarting has been slow.[14] Our analysis considers two scenarios for the role of nuclear power in Japan's energy mix—nuclear restart to the extent outlined in the Long-term Energy Outlook or a complete phaseout of nuclear power in Japan by 2030.

[12] Calculated based on production by sector as reported by industry associations, and emissions by sector as reported by the Greenhouse Gas Inventory Office of Japan.
[13] *Investing in climate, investing in growth*, first edition, Paris, France: OECD Publishing, 2017.
[14] According to the METI compilation of public opinion polls, in 2017–18, 20–35 percent of the public supported nuclear restart and 50–75 percent were against it; information adapted from the METI Electricity and Gas Industry Committee Nuclear Energy Subcommittee's 17th meeting on March 20, 2018.



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Priority measures for meeting the 2030 Paris Agreement targets

Our analysis identifies the most cost-effective measures to deliver 300 MtCO_2e of abatement needed from 2016 to 2030 across four key sectors. The Marginal Abatement Cost Curve (MACC) shows from left to right the most cost-effective measures that reduce GHG emissions (Exhibit 2).[15]

Detailed measures are grouped into similar buckets (Exhibit 3); we find there are three critical themes that can support overall decarbonization[16]:

Decarbonizing the power sector (174 MtCO_2e abatement) makes the largest contribution to achieving the 2030 emissions-reduction target. While the future of nuclear power in Japan is still unclear and under discussion, nuclear restart (112 MtCO_2e) is the single most impactful and cost-effective measure from a decarbonization perspective. Large-scale adoption of renewable energy, such as solar PV and onshore wind (62 MtCO_2e), also has a greater impact compared with measures from any other sector.

Lowering the energy demand through capacity retirement in residential buildings (15 MtCO_2e), industries (10 MtCO_2e), and passenger transport (6 MtCO_2e) makes the second-largest contribution to decarbonization. Natural population decline inevitably lowers energy demand and, thus, emissions.

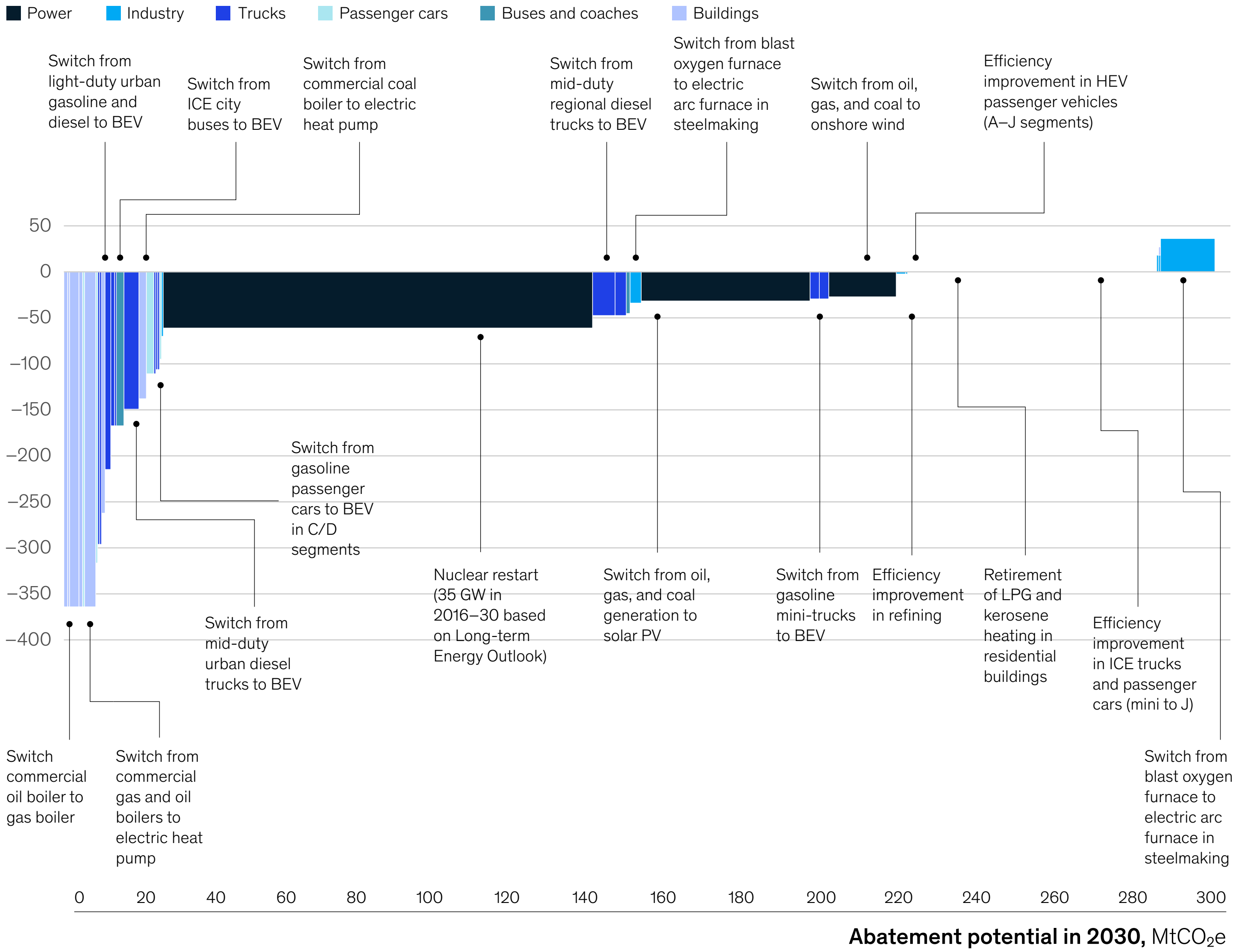
[15] Each block on the MACC represents an emissions reduction measure. The width of each block shows the annual emissions reduction potential in 2030 versus 2016. The height of each block shows the average cost of abating one tonne of CO_2e— the difference in total cost of ownership (TCO) of emission reduction technology versus current technology per tonne of CO_2e reduction.

[16] Abatement numbers below do not add up to 300 MtCO_2e, because of rounding.

Exhibit 2

The Abatement Cost Curve shows that 95 percent of abatement required for the 2030 Paris Agreement target can be achieved through cost-negative or cost-savings measures.

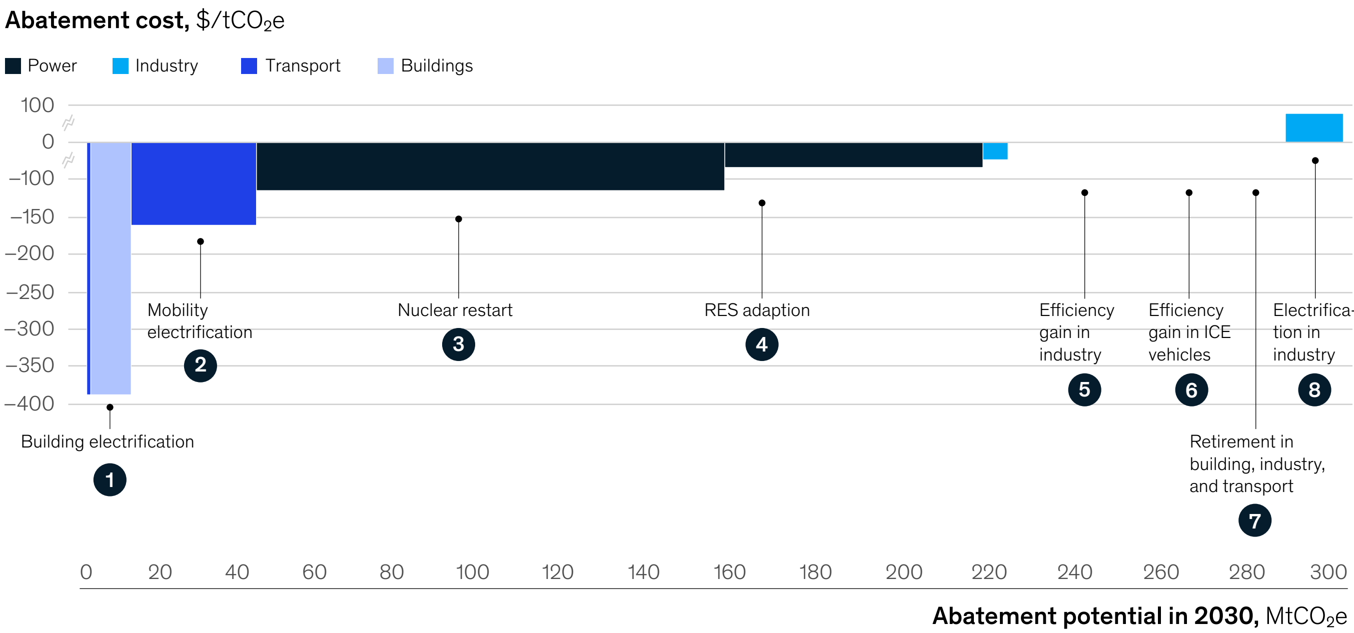
Average abatement cost, $/t$CO_2$e



Source: Decarbonization Pathway Optimizer by McKinsey Sustainability Insights

Exhibit 3

The 2030 emissions-reduction target can be achieved by eight buckets of measures.



Source: Decarbonization Pathway Optimizer by McKinsey Sustainability Insights

Electrifying the energy demand in buildings (11 $MtCO_2e$), transport (30 $MtCO_2e$), and industrial sectors (15 $MtCO_2e$) as well as *improving efficiency* in transport (34 $MtCO_2e$) and industry (6 $MtCO_2e$) are also crucial.

Most notably, our findings suggest that 95 percent of the abatement required to meet the 2030 Paris Agreement target can be achieved through measures that are cost neutral or that result in cost savings for Japan. In other words, these measures would result in total-cost-of-ownership (TCO) savings, which includes the initial investment costs and the operation costs for the full lifetime of the measure. These measures are made possible by the remarkable global trends that drive a rapid decline in costs for major decarbonization technologies, including battery electric vehicles (BEVs), heat pumps, and renewable power generation. The forecasted activity levels decline also brings cost-neutral emissions reduction.

At the sector level, we estimate that power, transport, and buildings will each reduce emissions by at least 20 percent by 2030 compared with 2016 levels (Exhibit 4). Drilling down, industry and buildings will have a smaller-scale reduction due to a projected increase in steel production and commercial floor area (either new buildings or the expansion of existing buildings).

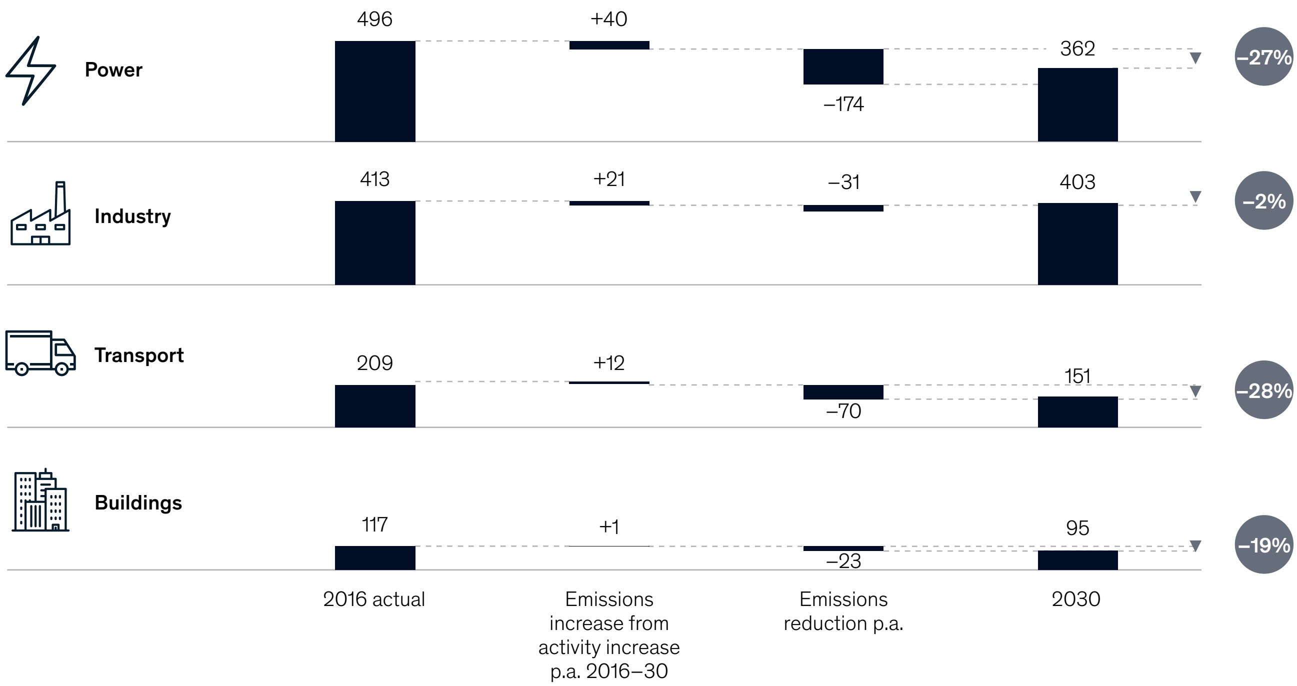
Power

The power sector accounted for 496 $MtCO_2e$ of emissions in 2016, making up 38 percent of total emissions, the largest share of Japan's sectors. Total electricity generation in 2016 was 1,053 terawatt hours (TWh), with 41 percent from natural gas, 33 percent from coal, 15 percent from renewables, 10 percent from oil, and

Exhibit 4

The largest abatements in the share of current emissions will come from transport and power sectors, followed by residential buildings.

Annual GHG emissions, $MTCO_2e$



2 percent from nuclear. In our analysis, electrification of end-use sectors is expected to increase electricity demand by 8 percent, leading to 1,139 TWh total electricity generation in 2030.[17]

According to our analysis of the most cost-effective measures to meet emissions-reduction targets, the power sector will account for 174 $MtCO_2e$ (58 percent) of the 300 $MtCO_2e$ required for emissions reduction by 2030—the largest contribution of all sectors. However, an 8 percent increase in electricity demand from increased electrification of end-use sectors leads to 8 percent emissions growth (40 $MtCO_2e$). Overall, we estimate emissions from the power sector in 2030 to be 362 $MtCO_2e$—a decrease of 134 $MtCO_2e$ (27 percent) compared with 2016.

The 174 $MtCO_2e$ abatement can be delivered by shifting the electricity mix away from oil, coal, and gas and toward zero-emission generation sources—primarily onshore wind, utility-scale solar PV, and nuclear. Changing the electricity mix will require investment to increase wind- and solar-generation capacity as well as to build the required infrastructure that will support the integration of variable renewable generation into the grid.

Considering the uncertain future of nuclear power in Japan, generation mix is analyzed in two scenarios. If nuclear plants fully restart based on the Long-term Energy Outlook (increasing the share of nuclear power to between 20 and 22 percent of the energy mix), it could provide 112 $MtCO_2e$ of abatement at an average savings of $64 per ton of carbon dioxide equivalent (tCO_2e). Another 62 $MtCO_2e$ of abatement

[17] This analysis optimizes Japan's generation capacity mix to meet demand from a system operator perspective, therefore it only considers centralized generation. Distributed generation adoption is driven by economic benefit from an end-customer perspective.

could be delivered by onshore wind and solar generation at an average savings of $33 per tCO_2e. This would involve increasing onshore wind generation's share of the electricity mix to 4 percent (15 GW generation capacity), up from less than 1 percent (four GW) in 2016, and solar's share to 12 percent (84 GW), up from 4 percent (39 GW) in 2016.

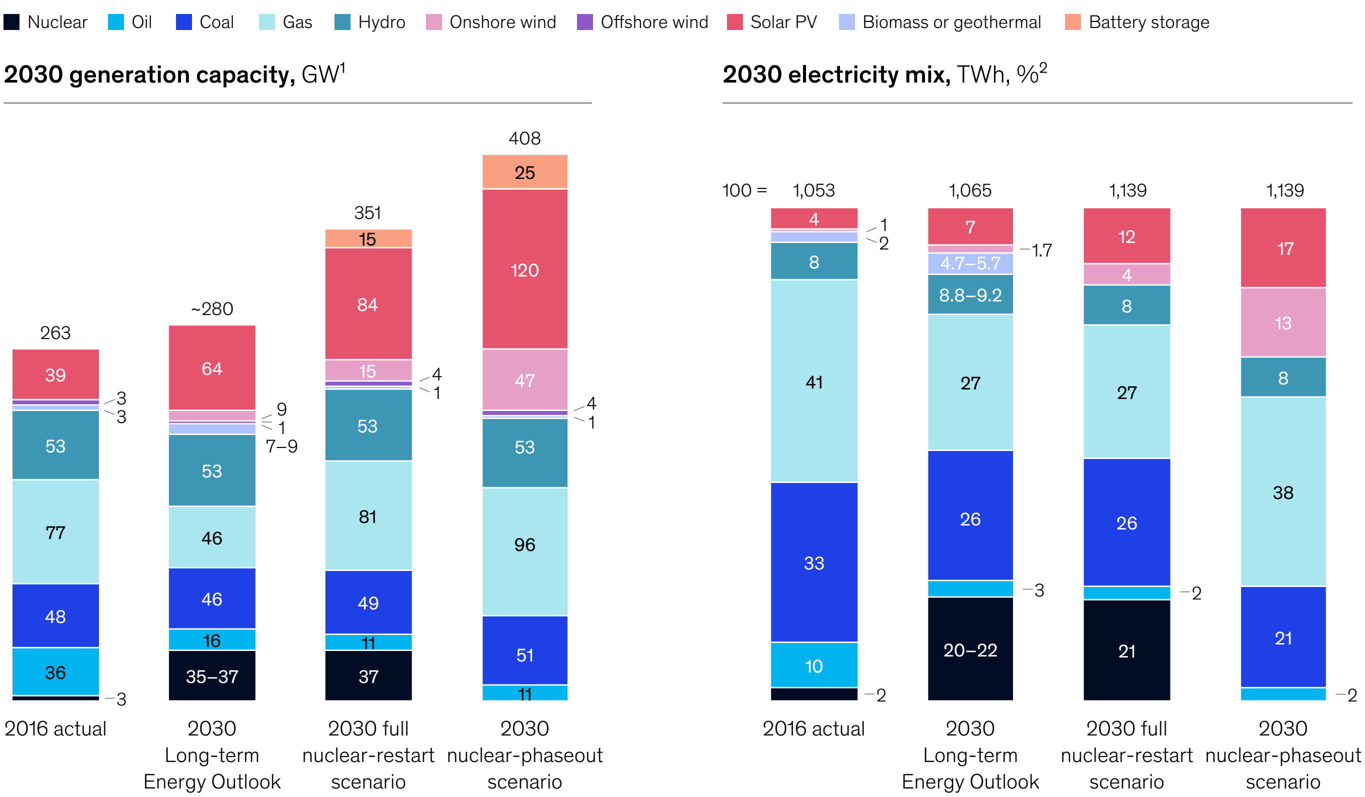
If nuclear power is phased out (Exhibit 5), additional solar and onshore wind will fill the 112 $MtCO_2e$ gap, providing the entire 174 $MtCO_2e$ abatement at an average savings of $25 per tCO_2e, compared to a higher average cost savings of $53 per tCO_2e[18] in the full nuclear-restart scenario. This would involve shifting the electricity mix to 13 percent onshore wind (47 GW) and 17 percent solar (120 GW). Both full nuclear-restart and nuclear-phaseout scenarios would involve a decrease in the share of electricity mix provided by coal, gas, and oil—but in the nuclear-phaseout scenario, reliance on gas generation will not slow as quickly. Gas will still make up 38 percent of the electricity mix in 2030, both to fill the gap for nuclear and to provide grid flexibility as variable renewable energy increases.

With the cost of renewable generation rapidly declining below the cost of conventional generation, the electricity mix described above is expected to lead to an annual electricity-generation cost of approximately

[18] Weighted average of 112 $MtCO_2e$ of abatement at an average savings of $64 per tCO_2e by nuclear restart, and 62 $MtCO_2e$ of abatement at an average savings of $33 per tCO_2e by solar PV and onshore wind.

Exhibit 5

Emissions reduction in the power sector can be achieved through increased adoption of solar, wind, and battery storage—regardless of the status of nuclear restart.



[1] Gigawatt; figures may not sum because of rounding.
[2] Terawatt hour; figures may not sum because of rounding.
Source: METI General Energy Statistics; Long-term Energy Supply and Demand Outlook; Decarbonization Pathway Optimizer by McKinsey Sustainability Insights

$73 billion in 2030 in both scenarios (6.4 cents per kWh), compared with $85 billion in 2016 (8.1 cents per kWH). Total savings in cost of generation through the 2016–30 time period amounts to approximately $100 billion in the full nuclear-restart scenario and $68 billion in the nuclear-phaseout scenario.

Achieving these cost savings will require a significant build out (2.3×–3.9× the current capacity) of onshore wind and utility-scale solar PV capacity. However, we believe this can be achievable for the following four reasons:

— *Japan has sufficient resource potential.* Japan is estimated to have 455 GW total solar PV and 169 GW total onshore wind resource potential.[19] However, our analysis suggests that even with accelerated renewables buildup in the nuclear-phaseout scenario, the 2030 projected solar and onshore wind generation capacity would only constitute 26 percent and 28 percent of the total resource potential.

— *Grid stability and security of electricity supply can be maintained.* Variable renewable resources would make up 15 to 30 percent of the electricity mix—similar to what European countries have been able to maintain today without compromising grid stability or security of electricity supply.[20] Furthermore, an addition of 15 to 25 GW of battery storage capacity (10 to 15 percent of Japan's peak demand[21]) and four to 18 GW of gas-generation capacity would also support the integration of variable renewable resources.

— *The potential for wind and solar cost reduction is significant.* The cost of renewable energy generation in Japan is two to three times higher than the global level today. The majority of the cost gap is due to regulatory burdens, immature supply chains, and limited industry growth to take advantage of economies of scale, while physical factors such as earthquake-prone geography are relatively inconsequential.[22] Cost-saving abatement opportunities can only be attained if concerted government and industry efforts push for cost reduction.

— *Japan has a track record of deploying renewable energy fast.* The projected 2030 solar and wind capacity requires an average annual new capacity of four to nine GW by 2030. At the end of 2017, Japan had approximately 53 GW of total installed solar and onshore wind capacity,[23] almost all of which was deployed over the past decade. This cadence translates into a historical average of approximately five GW of new capacity per year, which means an annual new capacity of four to nine GW is not unrealistic. Japan needs to revive its past speed of renewables deployment, including through policy incentives that accelerate infrastructure buildup, which can usually be a slow process.

Industry

Industry sectors accounted for 32 percent (413 $MtCO_2e$) of Japan's GHG emissions in 2016, making it the second-largest source of emissions after power. The largest contributors were iron and steel production (36 percent), cement production (10 percent), refining (9 percent), and pulp and paper (5 percent). The remaining contributions came from fluorinated gases and the CO_2 emissions from many other small industry sectors.

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[19] The assessment of onshore wind resource potential is based on conditions of more than 6.5 meters per second wind speed at 80 meters, as detailed by the Japan Wind Power Association. Solar PV resource potential is based on the Central Research Institute of Electric Power Industry and has been adjusted to make 10 percent of agriculture land, 100 percent of nonplanted agriculture land, and 100 percent of regnerable, abandoned agriculture land available for solar development.

[20] For example, Germany's 2018 electricity mix included 28.8 percent solar and wind. Professor Dr. Bruno Burger, *Net public electricity generation in Germany in 2018*, Fraunhofer Institute for Solar Energy Systems ISE, January 2019, ise.fraunhofer.de.

[21] Calculated based on peak demand of 156 GW in fiscal year 2017 according to the Federation of Electric Power Companies of Japan.

[22] Based on analysis by the Ministry of Economy, Trade and Industry, the Renewable Energy Institute, the Japan Wind Power Association, and the Japan Photovoltaic Energy Association.

[23] The following data is according to METI 2019 Energy white paper: 49.5 GW solar PV capacity at the end of 2017 and 3.66 GW onshore wind capacity at the end of 2018.

Our analysis shows the industry sector can contribute 31 $MtCO_2e$ (10 percent) of the total 300 $MtCO_2e$ required for abatement by 2030. Measures in the steel industry alone would make up more than 50 percent of this abatement potential. However, at the same time, a 15 percent growth in steel production[24] will also lead to 21 $MtCO_2e$ of growth in baseline emissions. As a result, overall industry sector emissions in 2030 are estimated to be 403 $MtCO_2e$—only a 2 percent reduction (10 $MtCO_2e$) compared with 2016.

In 2016, 80 percent of steel was produced using blast furnace–basic oxygen furnace (BF–BOF) technology. However, electric arc furnace (EAF) technology generates half the emissions compared with BF–BOF technology. Thus, shifting the steel industry from 20 percent EAF in 2016 to 29 percent in 2030 would lead to 14 $MtCO_2e$ abatement at an average cost of $37 per tCO_2e. In addition, a 5 percent energy-efficiency improvement for conventional BF–BOF technology would lead to three $MtCO_2e$ abatement at an average cost savings of $36 per tCO_2e.

Another 3 $MtCO_2e$ abatement could come from the electrification and efficiency improvement in refining at an average cost savings of $4 per tCO_2e.

Of the remaining 11 $MtCO_2e$ abatement in industry, 10 $MtCO_2e$ could come from capacity retirement due to a forecasted production decline in refining, cement production, paper making, and ethylene production. This potential highlights the importance of closely tracking and managing the evolution of Japan's industrial capacity to ensure that the least-efficient plants are retired and replaced.

Transport

In 2016, transport was responsible for 16 percent (209 $MtCO_2e$) of Japan's total emissions. This analysis focuses on road transport specifically, which contributes 80 percent (167 $MtCO_2e$) of transport-sector emissions. Within road transport, passenger cars account for 100 $MtCO_2e$, trucks account for 62 $MtCO_2e$, and buses account for six $MtCO_2e$.

Our analysis shows that road transport could contribute 70 $MtCO_2e$ (23 percent) toward the total 300 $MtCO_2e$ required abatement by 2030. Projected demand growth in commercial transport (trucks) is expected to lead to a 12 $MtCO_2e$ emissions increase by 2030. Overall transport-sector emissions in 2030 are estimated to be 151 $MtCO_2e$—a decrease of 28 percent (58 $MtCO_2e$) compared with 2016.

The most cost-effective measure would be switching from internal combustion engine (ICE) vehicles to battery electric vehicles (BEVs), which would lead to a 30 $MtCO_2e$ abatement at an average savings of $113 per tCO_2e. This shift will be enabled by drastically decreasing battery prices; BEV battery prices dropped 79 percent in just seven years, from $1,000 per kilowatt hour (kWh) in 2011 to $209 per kWh at the end of 2017.[25] Specifically, the switch from ICE vehicles to BEVs would include the following:

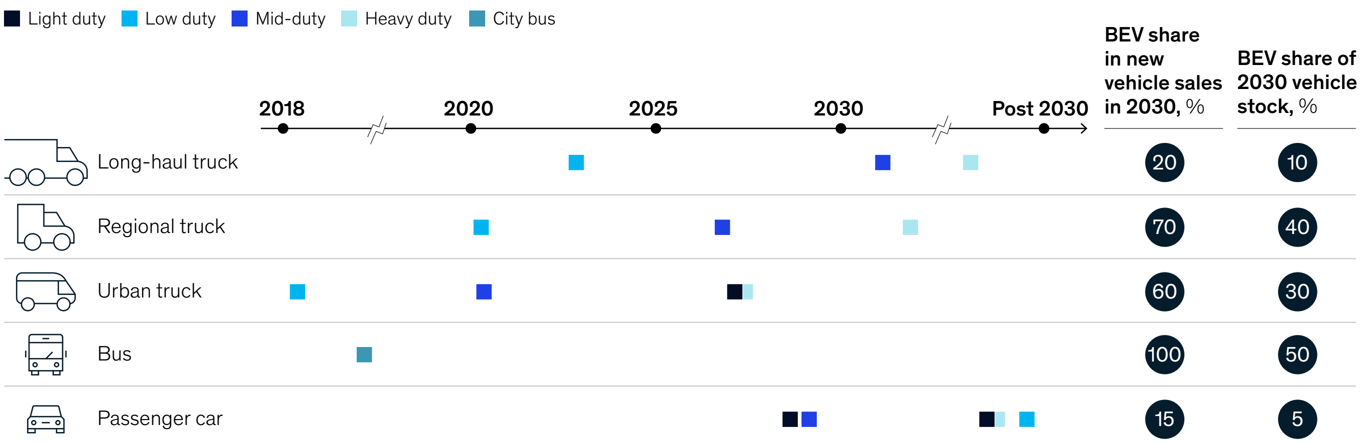
— *Battery electric passenger vehicles:* In 2030, approximately 2.6 million passenger BEVs could be on the road, and 18 percent of new passenger vehicle sales could be BEVs. We expect TCO parity—when total cost of ownership of alternative technology becomes equivalent to incumbent technology—to arrive in the late 2020s for low- and medium-duty segments and after 2030 for other segments (Exhibit 6). This is later than the expected TCO parity time in European countries[26] due to shorter average annual miles driven in Japan, which reduces the fuel-savings impact of BEVs compared with ICE vehicles.

[24] Steel production projection from "Long-term energy supply and demand outlook," Japan Ministry of Economy, Trade and Industry, enecho.meti.go.jp.
[25] Mark Chediak, "The latest bull case for electric cars: The cheapest batteries ever," *Bloomberg*, December 5, 2017, bloomberg.com.
[26] Nathaniel Bullard, "Electric car price tag shrinks along with battery cost," *Bloomberg*, April 12, 2019, bloomberg.com.

Exhibit 6

BEV reaches cost parity in most commercial vehicle segments before 2030.

Time of cost parity in Japan by vehicle segment



Source: Decarbonization Pathway Optimizer by McKinsey Sustainability Insights

— *Battery electric trucks:* In 2030, approximately 2.7 million BEV trucks could be on the road, and 49 percent of new truck sales could be BEVs. We expect TCO parity to arrive before 2030 for most truck segments, thus the higher rate of adoption compared with passenger vehicles.

— *Battery electric buses:* In 2030, approximately 48,000 BEV buses could be on the road, and 87 percent of new bus sales could be BEVs. This scale of electrification is in line with the commitments being made globally. In fact, 27 major cities, including Tokyo, have already signed the Fossil Fuel Free Streets Declaration, vowing to buy only zero-emission buses from 2025 onward.[27]

Another 34 $MtCO_2e$ abatement would come from efficiency improvement, assuming new non-BEV fuel use per kilometer falls by approximately 2 percent per year until 2025. Finally, retirement of passenger vehicles due to a forecasted 3 percent reduction in passenger vehicle miles driven would lead to six $MtCO_2e$ abatement.

The Japanese government's Basic Hydrogen Strategy calls for replacing 1,200 ICE buses and 800,000 ICE passenger vehicles with fuel-cell vehicles (FCVs), which would lead to one $MtCO_2e$ abatement at a cost of \$2,171 per tCO_2e.[28] Our analysis suggests TCO parity of FCVs is unlikely to arrive until after 2030. Economic viability for FCVs could come first for specific use cases, such as for heavy-duty long-haul segments where batteries would be too heavy, and for low-temperature environments where battery performance is limited.[29] However, it could make strategic sense to invest in FCVs from a technology-innovation and global industry-leadership perspective.

Electrification of road transport would require car owners to switch their purchasing behavior and decision-making criteria. The higher up-front cost of BEVs could still pose an adoption barrier even if TCO

[27] "Fossil Fuel Free Streets Declaration," C40, accessed July 7, 2019, c40.org.
[28] Not included in the 70 $MtCO_2e$ of total cost-effective abatement from the transport sector due to high cost.
[29] Steven Loveday, "Why electric cars don't like cold temperatures, and how to fix it," InsideEVs, February 6, 2019, insideevs.com.

parity is reached, requiring government and automotive manufacturers to introduce incentives (such as subsidies, tax credits, and preferential number-plate policies) and innovative financing programs to help consumers overcome this barrier.

Buildings

In 2016, buildings were responsible for about 117 $MtCO_2e$ of Japan's emissions, 61 $MtCO_2e$ of which came from commercial buildings and 56 $MtCO_2e$ of which came from residential buildings. Space and water heating rely heavily on fossil fuels. In residential buildings, 54 percent of space heating and 65 percent of water heating is provided by fossil fuels.[30] In commercial buildings, 95 percent of space heating and 70 percent of water heating is provided by fossil fuels.[31]

Our analysis suggests that the building sector could contribute 23 $MtCO_2e$ (9 percent) toward the total 300 $MtCO_2e$ of required abatement by 2030, primarily by replacing fossil fuel–based space and water heating with electric heating. At the same time, projected growth in commercial building floor space is expected to increase emissions from commercial buildings by one $MtCO_2e$ by 2030. As a result, overall building sector emissions in 2030 are estimated to be 95 $MtCO_2e$—a 19 percent reduction (22 $MtCO_2e$) compared with 2016.

The residential sector contributes 14 $MtCO_2e$ toward the abatement potential. An expected 13.0 million old homes will be retired by 2030, which would achieve a 15 MtO_2e abatement from the associated retirement of approximately 14.0 million kerosene devices and 9.5 million LPG devices.[32] Japan could also realize approximately one $MtCO_2e$ of abatement at an average cost savings of \$272 per tCO_2e from retrofitting the insulation of three million homes combined with replacing fossil-fuel heating devices with electric heat pumps.

Emissions reduction in the residential building sector is considered difficult because it requires individual homeowners to retrofit their space and water heating. Japan has a unique advantage in this case due to a preference to live in newly built homes.[33] Faster housing-stock turnover compared with other developed countries[34] aids the adoption of highly energy-efficient homes and heating devices. However, the contribution from retrofitting identified in this analysis is small and can be easily replaced by alternative measures in other sectors. Currently only 6 percent of homes in Japan comply with energy-efficiency guidelines for residential buildings.[35] A combination of building retirement, new builds, and limited retrofitting would increase this rate to 34 percent by 2030.

The remaining ten $MtCO_2e$ of building-sector abatement comes from electrification in commercial buildings at an average cost savings of \$413 per tCO_2e. This would be achieved by replacing gas and oil boilers for space heating in 20 percent of commercial buildings with 1.1 million commercial air-to-air heat pumps.

Buildings are long-lived assets. The energy efficiency of new builds today will lock in emissions levels for the next 40 to 50 years. Therefore, it is crucial to impose and ensure compliance with strict efficiency regulations—consistent with the best-available technology—for new builds.

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[30] In space heating, 40 percent by kerosene, 12 percent by gas, 2 percent by liquefied petroleum gas (LPG), 45 percent by electric air-to-air pump. In water heating, 34 percent gas, 19 percent by LPG, 12 percent by kerosene, 31 percent by electric air-to-air pump, and 5 percent by electric water heater. These numbers do not add up to 100 percent, because of rounding.

[31] In space heating, 69 percent by gas, 19 percent by kerosene, 6 percent by coal, 4 percent by electric air-to-air heat pump, and 1 percent by district heating. In water, heating, 42 percent by kerosene, 23 percent by gas, 5 percent by coal, 26 percent by electric air-to-water heat pump, and 4 percent by district heating.

[32] The number of devices exceeds the number of homes retired because Japanese homes typically have separate devices for water heating and space heating, as well as multiple devices for space heating in different rooms.

[33] "Why Japanese houses have such limited lifespans," *the Economist*, March 15, 2018, economist.com.

[34] According to Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) data, residential buildings in Japan are destructed at an average age of 32 years compared with 67 years in the United States and 81 years in the United Kingdom, mlit.go.jp.

[35] "National Adaptation Plan," Prime Minister's Office of Japan, May 13, 2016, kantei.go.jp.

Enabling infrastructure required

The appropriate enabling infrastructure is required to deploy the measures described above. Society as a whole must undertake these infrastructure investments, which typically do not influence individual citizens' decisions to switch to BEVs or renewable energy. Therefore, infrastructure investment costs are considered separately here and not incorporated into the abatement cost reported above. The scale of these investments does not reverse the business case for switching to EVs, increasing electrification, or increasing solar and wind generation.

The most important enabling infrastructure investments consist of the following:

Charging infrastructure for BEVs: A $9 billion investment would be required to deploy approximately 3.3 million chargers to support 5.4 million BEVs by 2030.[36] This is only 4 percent of the $225 billion total investment required for the full deployment of 5.4 million BEVs.

Grid reinforcement to accommodate growing electricity demand: Approximately $7 billion would be required,[37] primarily on the distribution grid, to accommodate peak load growth due to end-use sector electrification.

Grid reinforcement to accommodate increase in variable generation: Our analysis finds that approximately $27 billion to $69 billion in additional investment would be needed through the 2016–30 period for grid reinforcement in the full nuclear-restart scenario, while $64 billion would be needed for the nuclear-phaseout scenario.[38] These investments would cover the following:

— Approximately $2 billion to $16 billion for reinforcement of interconnections between grid areas.[39]

— Approximately $25 billion to $53 billion for reinforcement of the transmission and distribution grid within each grid area.[40]

Buildup of storage to balance electricity supply with demand: Approximately $4 billion to $8 billion would be needed for 15 to 25 GW of battery storage capacity.

In both the nuclear-restart and nuclear-phaseout scenarios, these grid reinforcement investments would cost just $0.03 per kWh when averaged over the total amount of solar- and wind-generation capacity from 2016 to 2030. In total, these investments are less than the $70 billion total savings in electricity-generation costs through 2016—$100 billion in the full nuclear-restart scenario and $68 billion in the nuclear-phaseout scenario. In addition, novel energy management solutions, such as demand-side management, can potentially reduce the need for grid reinforcement.

Since grid reinforcement cost is highly variable depending on local conditions of the grid and generation mix, the estimates above are only indicative of order of magnitude, while more-accurate cost estimates would require much more detailed assessment on a case-by-case basis.

[36] This estimate assumes one private wall charger per passenger BEV, ten conventional public chargers per 100 BEVs, and one fast public charger per 100 BEVs.

[37] Calculated based on capital cost of substation by type and size and modeled 8 percent growth in peak demand.

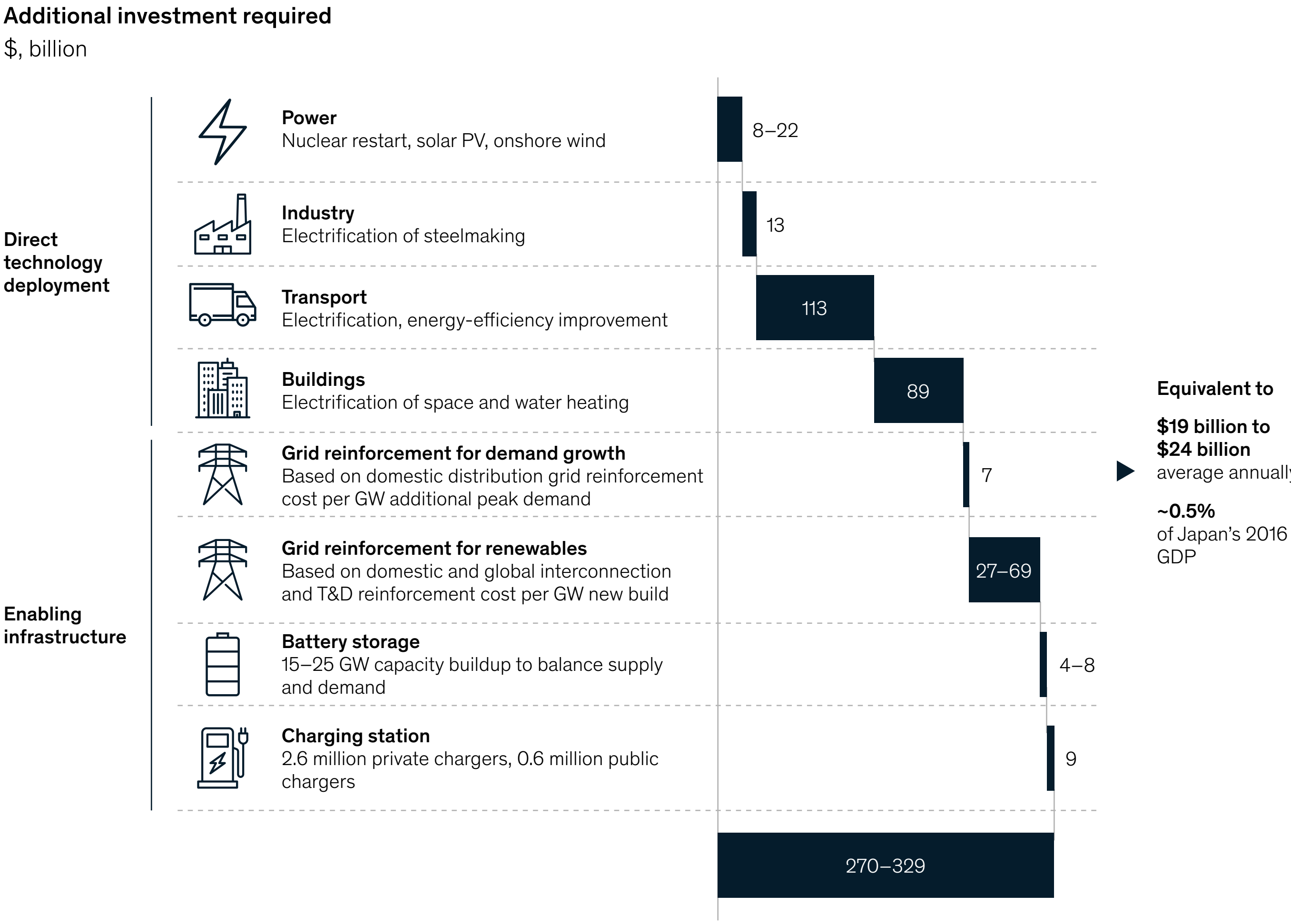
[38] Figures may not sum because of rounding.

[39] The range shows lower and higher end estimations based on 300 Yen/kW/km from average cost of planned/ongoing interconnection projects in Europe (Spain–UK, Spain–France, France–England, Norway–Germany, France–Italy, Germany–UK, Italy–Tunisia, Belgium–UK) and 1,396 Yen/kW/km from METI 2015 Generation Cost Validation Committee example for Hokkaido–Tohoku interconnection; interconnection capacity of 18–23 GW is added based on modeling of wind and solar buildup by interconnection region.

[40] Assumes the cost of transmission and distribution grid within each grid area is approximately 45,540 Yen per kW of additional solar and wind capacity based on example assessment for the Hokkaido–Tohoku region in the METI 2015 Generation Cost Validation Committee. The range shows estimations for full nuclear restart and nuclear phaseout scenarios.

Exhibit 7

Decarbonization requires $19 billion to $24 billion additional capital investment per year versus continuing 2016 technology mix.



Note: Range shows values for full nuclear-restart and nuclear-phaseout scenarios.

Source: METI Generation Cost Assessment Working Group; Decarbonization Pathway Optimizer by McKinsey Sustainability Insights

While the overall business case is clear, the need for established enabling infrastructure before technology deployment means larger lump-sum investments must be made in a shorter time frame to meet individual technology adoption targets in 2030. Of course, this capital deployment will be challenging given the physical limitations surrounding how quickly the infrastructure can be built. Government and industry should come together and agree on the mechanism for these investments as well as how to fairly distribute the up-front costs among stakeholders.

Required investment and its economic impact

While TCO-positive, many decarbonization technologies require higher up-front capital investment than conventional technologies—for example, an EV has higher up-front costs than an ICE vehicle despite having a lower lifetime cost for fuel and maintenance. The incremental up-front investment required poses an initial adoption barrier, but it also represents an opportunity to boost economic growth through stimulating investment.

Including the infrastructure investment as detailed above, we estimate that, depending on the nuclear scenario, deploying these measures would require an incremental up-front capital investment of approximately $270 billion to $329 billion between 2016 and 2030 compared with the investments required to maintain the 2016 technology mix (Exhibit 7). This translates to an average annual increase in investment of $19 billion to $24 billion, or 0.5 percent of Japan's annual GDP.

We estimate that decarbonization can realize up to 1.6 percentage points in annual positive GDP impact by 2030. This positive GDP impact comes from three aspects:

Incremental capital investment required for deployment of decarbonization technology contributes up to 0.5 percent positive GDP impact per year as detailed above.

Stimulation of economic activities indirectly by incremental investment—for example, increase in supply-chain activities and increase in income and spending of workers in decarbonization related industries—contributes up to 0.6 percent positive GDP impact per year. This is estimated using Japan-specific and sector-specific GDP multipliers (the additional GDP per unit of incremental investment, created indirectly through increased supply-chain activities and consumer purchase).[41]

Reduction in fuel import expense contributes up to 0.6 percent positive GDP impact. Electrification of end-use sectors and switching from fossil fuel to renewable power generation reduce dependence on fuel imports, which is particularly important considering Japan's nearly 100-percent reliance on import for fossil fuels.[42]

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[41] Sector-specific GDP multipliers for Japan used in this analysis is calculated from input-output table of Japan (World Input Output Database 2014) by McKinsey Global Institute Economics Research.

[42] *Japan's energy 2018: 10 questions for understanding the current energy situation*, Ministry of Economy, Trade and Industry Agency for Natural Resources and Energy, 2018, enecho.meti.go.jp.

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Beyond 2030: Pathway to the 2050 Paris Agreement target

Japan's 2050 Paris Agreement target of an 80 percent reduction in emissions (against the 2013 baseline) will require more drastic measures. Given the pace of technology advances we have seen in the past decade, it would be premature to predict the precise measures to support this level of emissions reduction. However, we can define six major technologies that will be crucial for Japan to meet its 2050 target, accounting for each technology's emission profile by industry, resource potential, and the current status of global development.

The most likely path to decarbonization across power, transport, and buildings comprises two main achievements: near-full electrification and a significant build-out of renewable electricity generation that is accompanied by storage.

Electrification of medium- and heavy-duty transport: By 2030, EVs in these segments could still be relatively expensive, especially for long-mileage categories. Success for post-2030 deployment will depend on progress in the next decade to further improve battery density and reduce battery price, as well as establish a strong supply chain for both batteries and EVs.

Offshore wind: Japan has more than 600 GW of offshore wind resource potential (including both floating and fixed-bottom generation). Our analysis suggests more than 100 GW of capacity buildup could be needed by 2050, compared with a mere 20 MW of installed capacity and 5.4 GW in the pipeline at the end of 2018.[43] Significant expansion of pilot projects and the supply chain, as well as overall cost reduction, is required for such an increase in deployment to be cost effective.

[43] "To expand offshore wind in Japan," Ministry of Economy, Trade and Industry, December 6, 2018, enecho.meti.go.jp.

Long-duration storage: Achieving 80 percent economy-wide decarbonization by 2050 requires almost complete decarbonization of the electricity system where variable renewable generation makes up about 80 percent of the electricity mix. Long-duration storage, which can cycle for days and potentially weeks in prolonged weather events, would be required to ensure stable electricity supply. While various long-duration battery technologies are also under development, hydrogen-based storage seems to be the most likely future technology option at this time.

In addition, Japan has significant emissions from hard-to-abate industrial sectors. The path to achieving an 80 percent reduction in these sectors is less clear than decarbonization in power, transport, and buildings. Breakthroughs in ongoing R&D efforts in the following three technologies are required:

Hydrogen-fueled technologies: These technologies can be applied across sectors. The most promising applications in industry are likely for cement and pulp production as fuel replacement as well as for steel and ammonia production as feedstock. In transport, hydrogen FCVs could be an alternative solution for the long-haul and heavy-duty segments, which are more difficult to electrify, but the long-term evolution of competitiveness versus BEV is still unclear.

In addition to R&D, cost-competitive hydrogen supply is a potential challenge for Japan. The cost of domestically produced hydrogen using renewable energy-based electrolysis is dependent on the cost of renewable energy supply in Japan, which still requires significant cost-reduction efforts. Importing hydrogen as an alternative supply route requires a scaled commercial supply chain (such as hydrogen carriers, terminals, liquefaction, and regasification facilities) to minimize logistics costs. However, industry is unlikely to invest in large-scale supply-chain infrastructure unless scaled demand is on the horizon. Leaders should decide on incentives for hydrogen adoption in priority industries to effectively spur scaled hydrogen demand.

Carbon capture, utilization, and storage (CCUS): CCUS will be required to reduce process emissions in cement, steel, and petrochemical production. However, the future of carbon capture storage (CCS) in Japan is unclear. One reason is a lack of suitable onshore storage locations, requiring costly long-distance, offshore transport.[44] However, Japan has high expectations for carbon capture and utilization (CCU) in carbon recycling applications that convert captured CO_2 from industrial processes into fuel and feedstock chemicals to be reused in industries. Hydrogen is used in many of these conversion processes, which means the success of CCU also partly depends on the adoption of commercialized hydrogen supply.

Electrification of high-temperature heat: The petrochemical and metallurgy industries can reduce emissions by electrifying high-temperature heat production. Most of the breakthrough technologies in this segment, such as electric cracking furnaces and iron-ore electrolysis, are still in the research or piloting phase but could enable significant replacement of coal and gas as industrial fuel. They will also need to be validated by their economic feasibility. Investing in R&D to foster technological breakthroughs and promoting pilot projects to test business models will be crucial in this next decade. Doing so will help ensure that new technologies will be ready for timely and scaled deployment well before 2050.

[44] *On current condition of CCS*, METI Global Environment Partnership Office, June 11, 2018, meti.go.jp.

Implementation mechanism to support climate change actions

Any decarbonization target would be meaningless without a rigorous and enforceable implementation mechanism. Many European countries have introduced or are proposing rigorous implementation frameworks on climate change.

The common elements of these frameworks—rigorous targets established under the consultation of independent advisory board that consider both the near and long term, delivered by cross-sectoral implementation mechanism with a clear line of accountability—could serve as a reference for Japan to create its own implementation mechanism (see sidebar, "Implementation mechanism for climate change actions in Japan").

Legal foundation for emissions-reduction targets: Writing emissions-reduction targets into national law puts legal responsibility to achieve the target onto the government and sets the foundation for relevant objectives to be prioritized in policy debates. Many major European countries, such as the United Kingdom, Germany, France, the Netherlands, Denmark, and Norway, have recently introduced new climate change laws alongside updated long-term emissions-reduction goals.

Long-term economy-wide targets accompanied by granular subtargets: Clarity on long-term targets and policy support is crucial for companies, particularly in sectors with long-lived assets, such as industry and buildings, in their investment decision making because investment today will lock in emissions in the next few decades. That said, targets also need to be specific and granular enough to enable detailed planning, progress tracking, corrective action, and accountability. National climate change laws typically require the government to set five-year carbon budgets that are consistent with long-term goals (such as in the United Kingdom,[45] Denmark,[46] Ireland,[47] and Germany[48]). In addition, some countries, such as Ireland and Germany, further require allocating the emissions budget to sectors and individual years.

Clear accountability mechanism: Accountability may come from two areas:

— *Clear designation of responsibility:* National emissions targets are allocated to sectors, such as in Ireland and Germany, and corresponding government ministers are typically responsible for their sector's targets. Responsibilities may include regularly reporting progress to the head of government or national assemblies, explaining gaps between performance and targets, and proposing plans to correct course in subsequent periods.

— *Financial consequences:* In European countries that have a regional emissions-reduction plan and a trading mechanism in place, national governments that fail to achieve emissions budgets are required to purchase allowances from other countries. For example, Germany has allocated €100 million per year from 2018 to 2020 for emissions-allowance purchases due to an expected failure to meet its binding emission targets under EU laws.[49]

Cross-sector transformation office: Global experience with large economy-wide transformation also shows that a cross-sector transformation office with an intensive coordination and escalation mechanism is required to manage a complex, economy-wide decarbonization transition. One example of such a transformation office is the Climate Action Delivery Board (CADB), which is currently under discussion in Ireland. On a weekly basis, the project management office of the CADB holds check-ins and joint problem-solving sessions with decarbonization-transition units within government ministries and among external stakeholders. Key issues from working-level sessions can be escalated to ministers for resolution in the weekly progress update. Remaining issues will be further escalated to the cabinet committee at progress-review meetings every four weeks. This organizational setup aims to:

— *Support effective issue resolution* through engaging across sectors, including public and private sectors

— *Foster strong decision-making power* through directly reporting to the highest level of government and involving all government ministry leaders

— *Encourage fast turnaround in decision making* through frequently engaging both working and leadership levels

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[45] "UK regulations: the Climate Change Act," Committee on Climate Change, accessed January 28, 2020, theccc.org.uk.
[46] "Danish climate policies," the Danish Energy Agency, accessed January 28, 2020, ens.dk.
[47] *Climate action plan*, Department of Communications, Climate Action & Environment, accessed January 28, 2020, dccae.gov.ie.
[48] "Climate action plan 2050: Germany's long-term emission development strategy," Federal ministry for the Environment, Nature Conservation and Nuclear Safety, accessed January 28, 2020, bmu.de.
[49] Kerstine Appunn, "Germany's climate obligations under the EU effort sharing scheme," Clean Energy Wire, May 6, 2019, cleanenergywire.org.

Implementation mechanism for climate change actions in Japan

While domestic laws reconfirm Japan's emissions-reduction targets under international treaties, national targets are framed as nonbinding best efforts rather than obligatory and allocated sectoral subtargets are viewed as guides. Therefore, when emissions-reduction targets are not met, there is neither a credible accountability mechanism at the national, local, ministerial, or industrial association level nor a legal foundation.

As outlined in Japan's 2016 National Adaptation Plan, emissions-reduction implementation and progress tracking are led by the Global Warming Prevention Headquarters under the cabinet office. These measures are guided by voluntary action plans from industry associations supervised by government ministries. The 2030 total national emissions-reduction target is allocated by sector. Once a year, the Global Warming Prevention Headquarters reviews the ministerial committee's progress report and introduces policy measures.

At the working level, industry associations develop emissions-reduction action plans, which include voluntary 2020 and 2030 reduction targets (in absolute emissions, emission intensity, energy intensity, energy use, and relative reduction versus business-as-usual flexibility depending on the judgment of the industry association) based on the best-available technology and annual progress reports, adjusting targets and implementation plans as technology evolves. These voluntary plans and progress reports are jointly reviewed by expert committees under the Ministry of Environment and the relevant industry ministries. Expert committees mainly consist of nongovernment officials, university and think-tank researchers, and stakeholders from nonprofit organizations and industry organizations.

An authoritative and independent advisory board: An independent advisory body for target setting, progress monitoring, and policy recommendation has become common practice in climate change governance.[50] The most prominent success story of such a body is the Committee on Climate Change (CCC) in the United Kingdom. A legally binding net-zero target for 2050 was adopted just one month after the CCC released its recommendations. Research on the CCC[51] shows its effectiveness comes from legal authority to perform its functions, legal requirements for the government to react on its recommendations in its annual progress assessment, trust in the expertise and subjectivity of committee members, some of whom are the most respected technical experts in relevant fields, and rigorous modeling and stakeholder consultation process in the formulation of recommendations.

[50] Alina Averchenkova, et al., The role of independent bodies in climate governance: the UK's Committee on Climate Change, October 2018, lse.ac.uk.

[51] Ibid.

Looking ahead

Achieving 95 percent of required abatement at neutral cost or lifetime cost savings is a unique opportunity for Japan compared with other developed markets. Japan's high technology costs and heavy reliance on fossil fuels across sectors, when compared with global levels, means it can realize greater cost savings and abatement potential with existing technology solutions. Natural population decline and industry activities can also serve as tailwinds.

In addition, investment for the deployment of decarbonization technologies and infrastructure, stimulation of economic activities along the supply chain of relevant industries, and reduced reliance on imported fossil fuels can contribute up to 1.6 percent.

However, change will not happen automatically. Challenges in all sectors remain, including the need to significantly reduce the cost of renewable energy, uncertainty in the future role of nuclear power, the potential loss of global competitiveness in industrial sectors, the uncertain cost trajectory for technologies, overall low public interest in climate change (resulting in low support for decarbonization policy changes), and the lack of an established implementation mechanism.

To address these challenges, Japan can consider the following steps:

Set climate change action as a national priority and introduce a credible governance mechanism: A symbolic message from the highest level of government could be crucial in prioritizing climate change nationally. For example, in June 2019, the government of Denmark ranked climate change above all other social programs in its manifesto.[53] In addition, it is necessary to establish a rigorous implementation mechanism.

[53] Chloé Farand, "Denmark's new government raises climate change to highest priority," June 26, 2019, Climate Home News, climatechangenews.com.

Align government and industry stakeholders on priority initiatives: Specific areas, such as the electricity mix, strongly influence whether Japan can achieve its overall emissions-reduction target.

In Japan, ambiguity and disagreements on the role of nuclear, renewables, and fossil fuels in the electricity system threaten achieving its Paris Agreement commitment. Thus, decisions on the future of nuclear are critical. Agreement from government and industry groups on the required scale of adoption as well as key regulatory barriers for renewable energy will be critical.

Our analysis identified electrification in transport, residential building, and steelmaking as the next most cost-effective measures. Coordinating leaders and cross-industry groups on priorities and the achievable scale of contribution from each area is critical. An alternative solution should be agreed upon if a target becomes unachievable.

Projected growth in domestic steel production is expected to be the single largest source of emissions growth and dwarfs the positive impact of cost-effective emissions-reduction measures in the industrial sector. Given the need for alternative measures by other industries, aligning government and players in the steel industry on a future growth trajectory is critical.

Offer incentives for the promotion of decarbonized technologies: Decarbonization by 2030 can be achieved by technologies that have matured or are maturing globally, such as large-scale renewables and the electrification of road transport. However, Japan still lags in the commercialization and adoption of these technologies. Leaders and industry groups can work together and agree on a short list of priority technologies that are key to Japan's decarbonization journey, while identifying cost and investment gaps for large-scale deployment. Leaders might also introduce incentives and regulatory changes, and industry groups could establish cost-reduction plans, R&D goals, and business-model changes to close these gaps.

Certain technology areas, such as buildings, have longer asset lives, meaning near-term investment decisions could lock down long-term emission trajectories. Government leaders could identify these areas, ensuring that regulations reflect the best-available technology standards.

In addition, long-term deep decarbonization requires technologies that are not yet mature. Agreement between government, industry groups, and research institutes on key technologies requiring significant R&D investment is critical and doing so can inform a road map for commercialization.

Raise awareness of combating climate change: Citizen support is essential both for generating the political will to set climate change action as a national priority as well as for implementing actions in consumer-facing sectors—such as electrification of residential heating. Financial investors should consider communicating the risks of climate change to political leaders and corporations. In addition, government, corporations, and the media can increase their public communication on climate change. By doing so, they could be more open about how the consequences of climate change affect livelihoods and businesses and clarify the links between individual action and positive change.

Long-term, it is crucial to:

Monitor global technology development and adjust industry policy accordingly. Long-term deep decarbonization requires technologies (for instance, hydrogen and CCS) for which future R&D and cost evolution is still uncertain. Government and industries can closely monitor the trajectory of technology development and periodically reevaluate the best-fit technology for decarbonization, such as BEVs versus FCVs and hydrogen versus offshore wind power generation, adjust the level of incentives for research and deployment, and reallocate the appropriate emissions-reduction contribution target by industries.

Develop a plan to make decarbonization attractive to globally competitive and traded industries. Decarbonization in the industrial sector is less essential for the 2030 emissions-reduction target, however, it is necessary for 2050—particularly for Japan due to its high share of industrial emissions. Decarbonization in globally traded commodity sectors, such as steel and chemicals, is challenging because investing in emissions reduction by players in one country under regulatory pressure might mean losing competitiveness to players in other countries with less ambitious emissions-reduction goals. Mechanisms that both encourage decarbonization and support fair competition—for example, through innovative carbon-accounting rules on imported goods (which requires agreement and collaboration among world governments) or through directly supporting domestic industry's investment in decarbonization—can help maintain competitiveness.

Contribute to global decarbonization through exporting technologies and sharing knowledge. Japan might focus on areas in which it is a global leader in technology development, including hydrogen-based technologies across industries, carbon recycling, and high-efficiency power equipment.

Japan can meet its 2030 emissions-reduction targets with matured technology that reduces costs and stimulates economic growth. However, government and industry will need to provide leadership to achieve this goal. Establishing decarbonization as a priority, aligning on targets and gaps, introducing the right policy incentives, and building a credible implementation mechanism will be crucial for Japan to realize this opportunity.

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Appendix: Notes on our methodology

Decision making for decarbonization is complex. While this report focuses on economic cost optimization, both the Japanese government and its citizens should consider factors other than economic cost in choosing the best possible path for Japan's decarbonization. These factors include public opinion or acceptance of certain technologies, such as a full nuclear restart or not-in-my-backyard attitudes regarding power plants; the feasibility and costs of enacting necessary policy changes, such as the adoption of incentives to overcome the up-front capital investment barrier; and the results of decarbonization measures, such as improved air quality.

With this in mind, we assessed more than 350 emissions-reduction measures on a year-by-year basis and optimized the total cost of ownership (TCO) across all sectors each year to determine the most cost-effective measures to meet Paris Agreement targets. To objectively compare different abatement options, the TCOs are considered from a system perspective—in other words, what the costs or savings are from the perspective of Japan as a whole—not including taxation on consumers or companies. A weighted average cost of capital of 4 percent was used across all technologies, as it takes a social perspective, and is equivalent to the social discount rate used in cost-benefit analysis of policies by Japanese governmental agencies.[54] TCO considers the cost of the stand-alone technology and does not include the costs of enabling infrastructure, which are separately assessed. For each measure, we also included a perspective on the future evolution of the technology, such as cost and efficiency improvements.

For all analyzed sectors, economic optimization is done by simulating technology switching on a year-to-year basis based on the age of existing assets, asset lifetime (therefore rate of retirement), and the new asset deployment required to meet demand.

For the power sector, in addition to year-to-year asset retirement or buildup, an hourly dispatch simulation based on local electricity load profile and renewable-resource profile ensures that the real-time balance of supply and demand and minimum requirements on system reliability are met. Potential electricity demand growth from electrification of end-use sectors for decarbonization is considered and met by additional generation capacity buildup.

For end-use sectors, demand projection for 2030 comes from the Ministry of Economy, Trade and Industry's Long-term Energy Supply Demand Outlook and local industry associations. Projection for 2050 assumes trajectory toward 2030 slows down or continues, depending on the industry. Demand-reduction mechanisms except for energy efficiency, such as behavior-based energy saving and demand response, are not considered due to uncertainty in quantification.

Our analysis focused on CO_2 emissions from four sectors: power, industry, transport, and buildings. These figures are based on primary energy consumption. Total GHG emissions from the four sectors, 95 percent of which is CO_2 emissions, make up 79 percent of Japan's total GHG emissions. In total, this focus covers approximately 75 percent of Japan's total GHG emissions.

Finally, our analysis is not a forecast of what Japan would look like in 2030 if the current technology and policy trajectory continues. Rather, it is an analysis of what changes should occur for Japan to meet its Paris Agreement targets and the potential technology mix that could be achieved when various challenges are properly addressed.

[54] "Summary of 2019 policy cost analysis," July 26, 2019, Ministry of Finance, mof.co.jp.