NDC ASPECTS

Country Report

Transition pathways for Japan

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Key messages

- Japan is a major economy located in East Asia part of the Pacific Ring of Fire, and the Japanese islands are prone to destructive earthquakes and tsunamis. The Fukushima disaster in 2011 had a major impact on Japan's development and future energy policy.
- Japan is a founding Party of the United Nations Framework Convention on Climate Change (1992) and has ratified the Paris Agreement since 2016. The country has submitted its Intended National Determined Contribution in 2016 and in the updated version of 2021 Japan made a commitment for more ambitious 2030 targets, while in 2020 the country declared a net-zero emissions target for 2050.
- The country is relatively poor in natural resources such as oil, gas, and minerals, and the energy sector is heavily dependent on imports, making energy security a national priority. In 2022, Japan's energy supply relied on net imports for 90 percent.
- The decarbonization pathway of Japan requires significant investments in renewable energy infrastructure, advancements in energy efficiency, and nuclear power plants and relevant infrastructure , and the adoption of stringent emissions reduction policies across all sectors of the economy to enable sectoral electrification and decarbonization of the energy supply.

Introduction and overview

Japan is an island nation in East Asia, renowned for its rich cultural heritage, technological advancements, and significant global economic influence. Despite being a resource-poor country that depends on imports for its energy, Japan is one of the world's largest economies and a major industrial player especially in automotive, electronics, and robotics. Situated along the Pacific Ring of Fire, Japan lies across four tectonic plates and is therefore prone to earthquakes: nearly 20% of the world's large earthquakes happen in the country. A strong earthquake occurred on March 11, 2011, leading to the Fukushima disaster, a catastrophic nuclear accident caused by the subsequent tsunami, leading to widespread radiation release and significant long-term impacts on Japan's energy policy and public health.

Key socio-economic figures and outlook

Japan is currently the 10th most populous country in the world with a population of 122 million inhabitants [1], [2]. Japan's population is projected to decline with an average annual rate of 0.6% up to 2050 mainly due to factors such as low birth rates and an aging population. In 2050, the Japanese population is expected to be approximately 104 million people [2].

Japan is characterized by a strong economy and the country ranked third globally in 2022 with a real GDP of 4.5

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trillion US$'2010 [3], [4]. The country's GDP is primarily distributed across three main sectors. In 2022, the largest sector was the services sector with a contribution of 72%, followed by the industrial sector with 27% and agriculture, which contributes only 1% to Japan's overall GDP [5]. The GDP of Japan is projected to increase with an average annual growth rate of 1% over 2025-2050 and is expected to reach 5.4 trillion US$'2010 in 2050. Japan is distinguished by its high standards of living and advanced economic status among developed nations; GDP per capita in 2020 was estimated at 31,653 US$'2010 and is projected to reach 51,727 US$'2010 in 2050, increasing with an average annual rate of 1.65% .

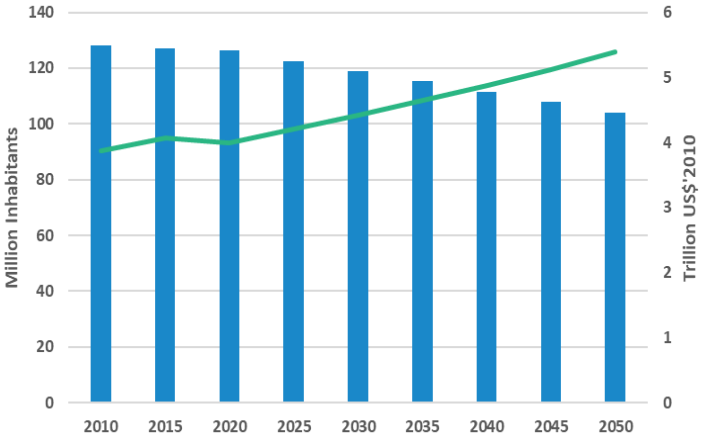

Figure 1: Japan's expected population and GDP development.

Current emission situation

Japan is one of the world's largest GHG emitters, constantly ranking in the top positions among countries globally [6]. Japan's GHG emissions peaked in 2013 reaching 1410 $MtCO_2eq$ [7] and 2013 was selected as the base year for the country's NDC emissions reduction targets. This peak was largely a result of increased reliance on fossil fuels following the Fukushima nuclear disaster in 2011. After the disaster, Japan shut down or suspended many of its nuclear reactors due to public opposition and safety concerns. Carbon-free nuclear energy, which covered 30% of Japan's electricity needs at the time, went down to almost zero by 2014. From 2013 to 2022, with a temporary interruption due to the recovery of the COVID-19 pandemic in 2021, Japan's emissions have been on a decreasing trend with an average annual decline rate of approximately 2% standing at 1170 $MtCO_2eq$ in 2022.

The contribution of different emitting sectors has remained relatively constant in the 2013-2022 period. The most carbon intensive sector is the energy sector (including both energy supply and energy demand sectors) contributing 87% of total emissions in 2022. The large share of energy-related emissions is mainly due to the high dependency on fossil fuels, especially in the years after the Fukushima disaster, and the high industrialization of the Japanese economy. Emissions of industrial processes and product use are steadily increasing and in 2022 contributed to 9% of total emissions, while the agricultural and waste sectors contributed to the remaining 4%.

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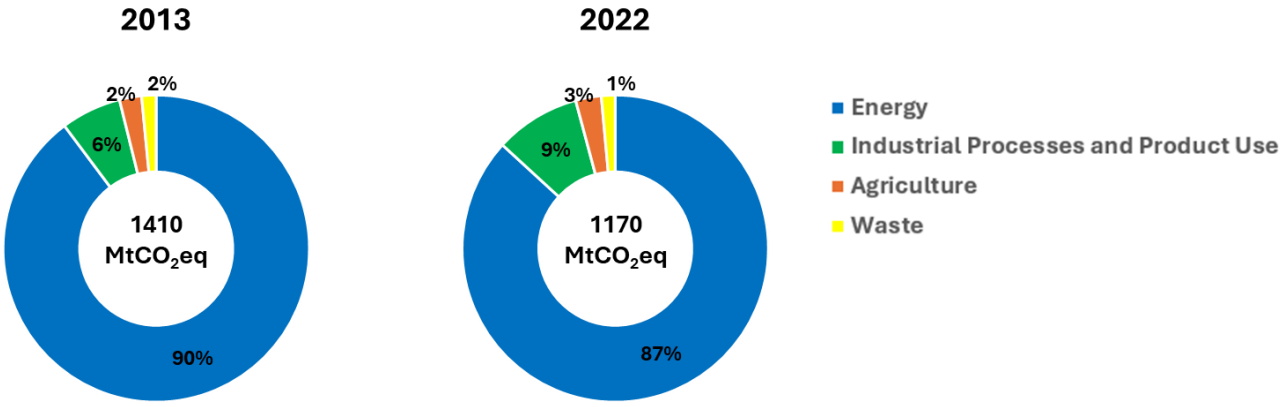

Figure 2: Japanese GHG emissions by sector in 2013 and 2022

The level of CO_2 emissions per capita in 2013 was 11.06 tCO_2eq and decreased to 9.31 tCO_2eq in 2022. The downwards trend of the GHG intensity of the Japanese economy was interrupted in 2011, following the Fukushima nuclear disaster, and reached the decade's peak, at 297 tCO_2eq/million $ GDP, in 2015. In the following period, the GHG intensity of economy decreased towards the value of 2011, exhibited a slight increase during the recovery of the 2019 COVID pandemic and the estimated value of 2021 is 237 tCO_2eq/million $ GDP.

National targets (NDCs) and programs/policies

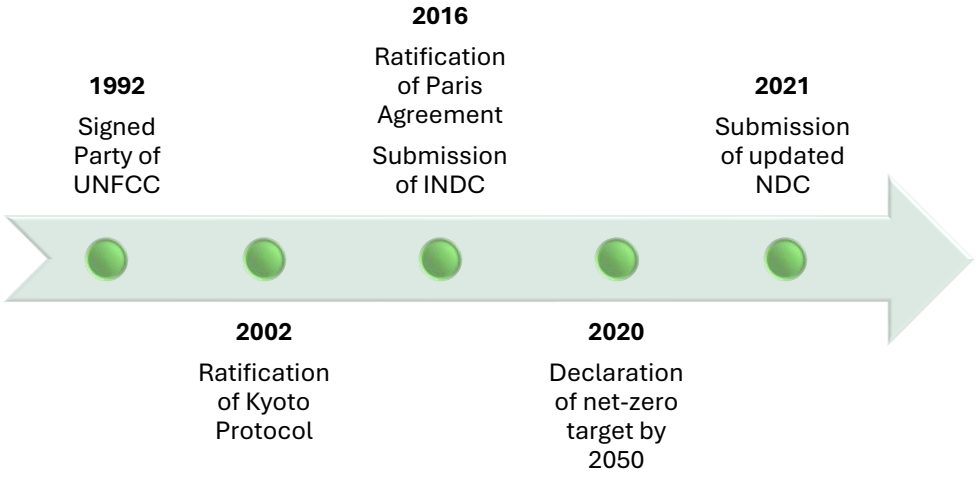

Figure 3: Timeline of Japan's climate pledges.

Japan is a founding member of the United Nations Framework Convention on Climate Change (UNFCCC) which was adopted in 1992. Japan ratified the convention on 1993 and as a founding member, Japan has been actively involved in the UNFCCC from the beginning. Japan hosted the Third Conference of the Parties (COP3) to the UNFCCC in Kyoto in 1997, where the Kyoto Protocol was established, and the country's ratification of the Kyoto Protocol followed in 2002. Japan ratified the Paris Agreement in 2016 and Japan's commitments under the Paris Agreement are detailed in its Nationally Determined Contributions (NDCs), the first version of which was submitted in the same year. In 2020, Japan's prime minister announced the country's aim to achieve net-zero emissions by 2050 and in 2021 Japan submitted an updated version of the country's NDC [8].

Japan revised its initial NDC target of reducing economy-wide GHG emissions by 26% by 2030, to a more ambitious goal of reducing GHG emissions by 46% compared to the national GHG emissions of 2013, the year that marked Japan's peak emissions in the aftermath of the Fukushima disaster. The current NDC target for 2030 is aligned with Japan's long-term target (LTT) and the commitment of achieving carbon neutrality by 2050.

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Key decarbonization pathways

This study explores a feasible decarbonization pathway for Japan, aligning with its NDC and long-term climate targets, and examines its impacts on the energy sector. The Japanese baseline scenario, or "business-as-usual" (BAU) pathway, assumes that no additional climate policies are imposed beyond those currently in place. In contrast, the decarbonization scenario (NDC/LTT) is based on emission reduction targets set in Japan's NDC for 2030 and aims for net-zero emissions by 2050, so it's a target-based scenario defined to meet Japan's emissions reduction targets for 2030 and 2050. Comparing the NDC/LTT scenario with the BAU scenario helps to assess the effectiveness and impacts of Japan's climate policies and measures. Projections for both scenarios are derived from the EDS model [9], a fully-fledged energy demand and supply simulation model aiming at addressing energy system analysis, energy price projections, power generation planning and climate change mitigation policies.

CO_2 emissions and NDC & LTT targets

The projections of energy-related CO_2 emissions, for both Baseline and NDC/LTT scenarios, are depicted in Figure 4. In both scenarios, annual CO_2 emissions are expected to constantly decrease in the period 2025-2050. In the Baseline scenario, the currently active climate policies of Japan lead to an average annual reduction rate of 1.5% up to 2050 and energy-related CO_2 emissions are projected to amount to 872 $MtCO_2$ and 616 $MtCO_2$ in 2030 and 2050 respectively compared to 981 $MtCO_2$ in 2020. In the BAU scenario, Japan does not achieve its NDC and long-term climate goals. Current policies achieve a 29% reduction of energy-related CO_2 emissions in 2030 relative to 2013 against the NDC target of 46% and emissions in 2050 are far from Japan's 2050 net-zero goal. The most carbon intensive sectors are the energy supply and transport sector which contribute to over 60% of total energy-related CO_2 emissions in 2050 (Figure 5). In the Baseline scenario, decarbonization efforts focus more on the energy supply sector while demand-side emissions are projected to remain relatively constant; this is a result of increasing economic activity and income that is counterbalanced by energy efficiency improvement in the demand sectors (transport, buildings, industries).

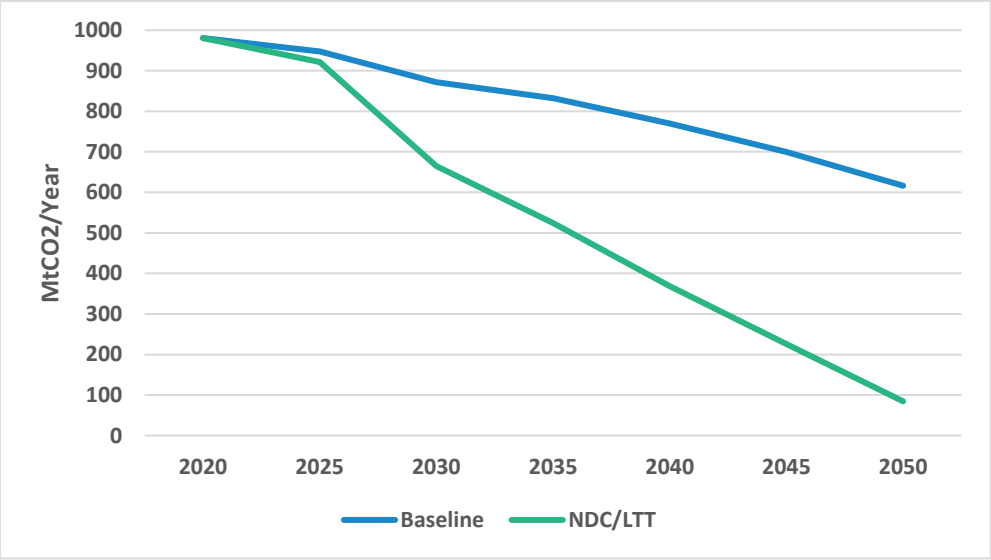

Figure 4: Projections of energy-related CO_2 emissions in Japan

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The decarbonization pathway of the NDC/LTT scenario includes the implementation of strong climate policies to support the country's NDC and LTT targets. In 2030, CO_2 emissions are projected to be 665 $MtCO_2$, achieving the 46% emissions reduction NDC target relative to 2013 (base year) and by 2050, energy-related CO_2 emissions decrease to only 84 $MtCO_2$, a more than 93% reduction compared to the 2013 levels. In the period 2025 to 2050, an average decrease rate of approximately 9.1% is estimated for annual energy-related CO_2 emissions and all sectors significantly reduce their emissions level. By 2050, carbon neutrality is achieved in the buildings and energy supply sectors with some residual emissions only in the industrial and shipping sectors, which can be compensated with the use of Carbon Capture, Use and Storage (CCUS) technologies.

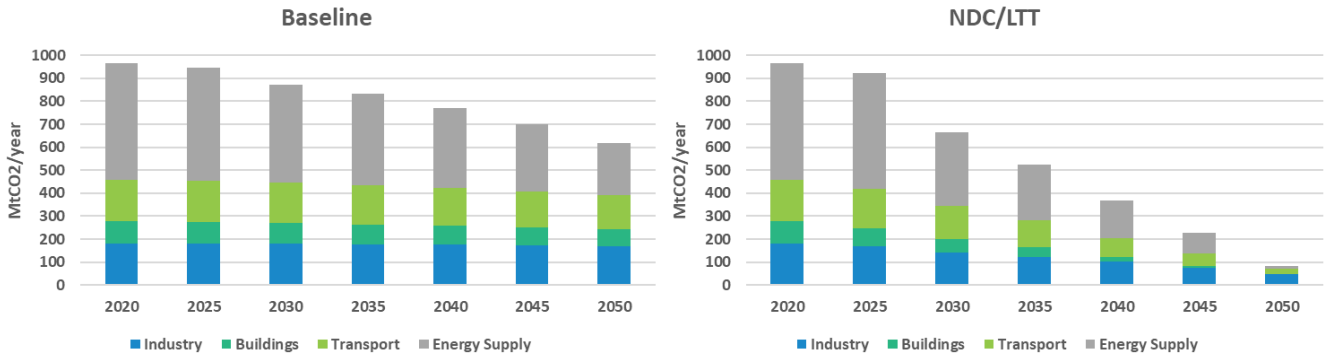

Figure 5: Projections of energy-related CO_2 emissions by sector

Impacts of Japanese NDCs on Final Energy Demand and Primary Energy Consumptions

The projections of final energy consumption, for both Baseline and NDC/LTT scenarios, are illustrated in Figure 6. In the Baseline scenario, final energy demand is projected to remain relatively constant with a negligible increase in the period 2020-2050; average annual increase rate is less than 0.2%. The 1% annual rise of economic activity driving the increase in final energy demand is counterbalanced by enhanced energy efficiency, and the uptake of more efficient equipment, appliances, and technologies across demand sectors (industry, buildings, transport). Electricity demand is increasing in the Baseline scenario, with Japan projected to remain dependent on fossil fuels, as (imported) oil, gas and coal are projected to cover over 55% of final demand in 2050. Final energy consumption in the NDC/LTT scenario has a decreasing trend as energy efficiency further improves, while more efficient fuels and technologies replace the use of fossil fuel-fired options (e.g. electric vehicles, heat pumps). Electricity substitutes a large portion of fossil fuels in comparison with the Baseline scenario and the overall energy efficiency is improved; in the NDC/LTT scenario, electricity becomes the backbone of Japan's energy system accounting for about 59% of the total final energy use. The revised Japan's NDC should focus more on the acceleration of energy efficiency improvements and the electrification of energy and transport end-uses in order to ensure a cost-efficient transition towards decarbonization, while reducing its energy import dependence and improving air quality.

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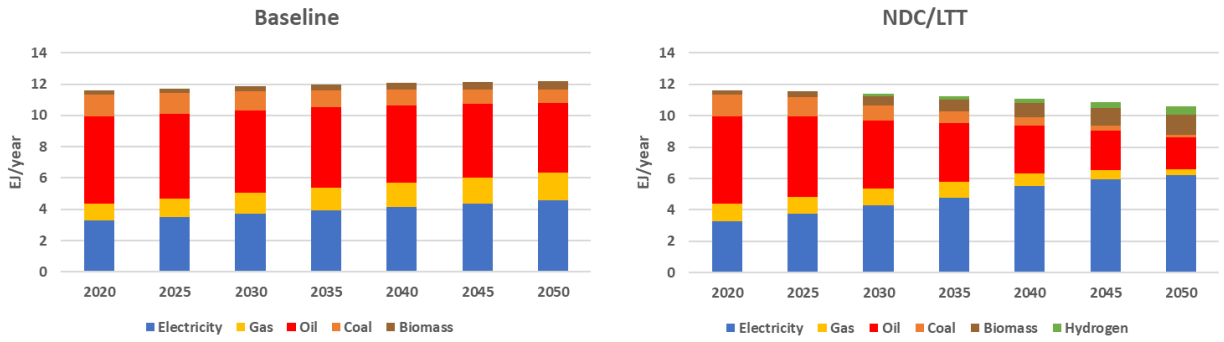

Figure 6: Japan's final energy consumption by fuel in Baseline and NDC/LTT scenarios

In both scenarios, primary energy consumption slightly increases after 2020 with a peak reached in 2030 in the Baseline scenario and in 2025 in the NDC/LTT scenario (Figure 7), followed by a gradual reduction in both scenarios. The annual decrease rate in the Baseline scenario is relatively small (0.3% annually over 2030-2050), however in the NDC/LTT scenario the average decrease rate increases to nearly 1% driven by the larger share of more efficient energy sources (solar, wind and hydro) relative to the Baseline. In 2020, the share of renewables in Japan's primary energy mix was only 6%. In the Baseline scenario, this share increases to 13% and 28% in 2030 and 2050 respectively, while in the NDC/LTT scenario the share of renewable energy is projected to reach 21% in 2030 and 53% in 2050. Nuclear energy was significantly reduced following the Fukushima disaster and in 2020 constituted 3% of Japan's primary energy. Currently active climate policies in the Business-as-usual scenario necessitate the increase of nuclear energy through the gradual use and re-activation of the nuclear power plants that were shut down after the Fukushima disaster; as a result, the share of nuclear power increases to 10% in 2030 and 15% in 2050 in the Baseline scenario. The NDC and long-term targets of Japan require a more significant contribution of low-carbon nuclear energy to decarbonize the country's power mix and the nuclear share in the NDC/LTT scenario reaches 16% and 29% in 2030 and 2050 respectively. However, the revival of nuclear power – including additional newbuilt capacities- comes with several societal, political, economic and environmental challenges, but the scenario reflects the official nuclear strategy of Japan. Other decarbonization pathways may also be relevant for the country, but the limited potential for several renewable energy sources (wind, biomass, hydro) makes nuclear power a relevant and necessary option for Japan to meet its net-zero target for 2050.

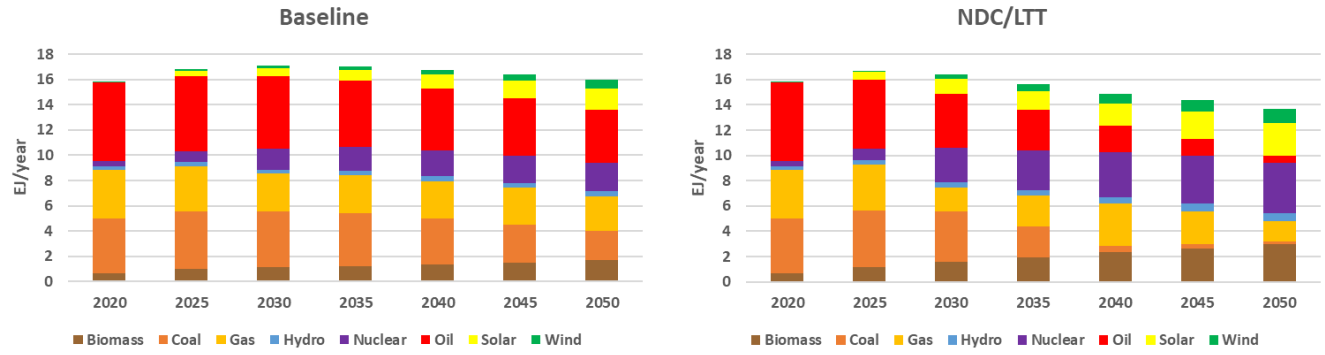

Figure 7: Japan's primary energy consumption by fuel in Baseline and NDC/LTT scenarios

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Sectoral system transformations

Industry

The industrial sector in Japan is diverse and highly developed, playing a crucial role in the country's economy and exports. In the Baseline scenario, the growth in industrial activity, combined with the absence of strong climate policies prevents decarbonization of the sector, with over 56% of final industrial demand covered by fossil fuels even in 2050, with coal, oil and natural gas playing a key role in the industrial energy mix. In contrast, in the NDC/LTT scenario, the (direct and indirect) electrification of the industrial sector accelerates with electricity and hydrogen replacing the use of fossil fuels and particularly oil and coal in major industrial sectors, i.e. steel-making, cement, chemicals, vehicle manufacturing, electronics etc. This leads to the overall reduction of final industrial energy demand (triggered also by the implementation of moderate circular economy measures), an increasing electrification of the sector up to 60% in 2050 and a reduction of industrial emissions by 73% in 2050 relative to the Baseline scenario – in part triggered also by the emergence of CCS to remove residual emissions from industrial processes- , paving the way for the transition of Japanese industries towards a low-emission, sustainable and circular paradigm.

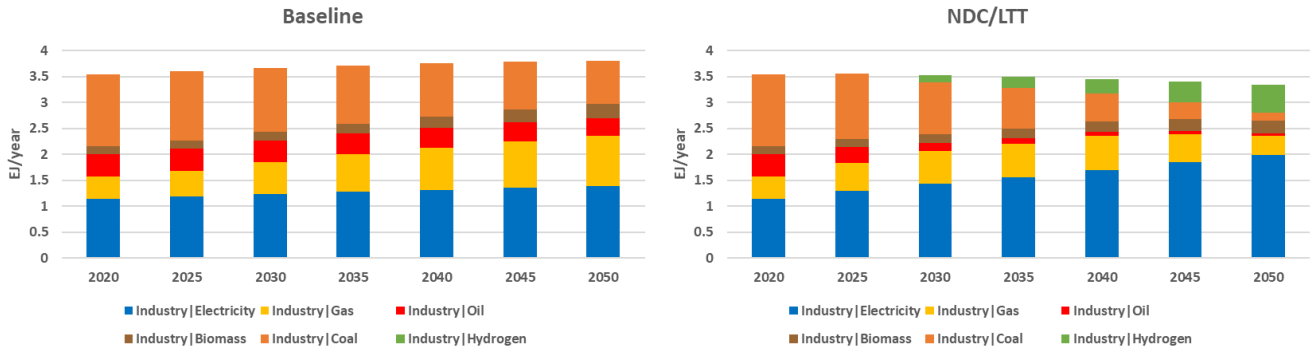

Figure 8: Final energy demand in the industrial sector by fuel

Transportation

The transport sector is currently the most carbon intensive demand sector of Japan as it is dominated by oil-based fuels which currently account for about 94% of the energy consumed by Japan's vehicle fleet, with electricity being the main fuel used for rail transport. In the Baseline scenario, the sales of electric and hybrid vehicles steadily increase and thus electricity consumption in the transport sector reaches a share of 19% in transport's energy mix by 2050. The electrification of transportation vehicles and infrastructure is more prominent in the decarbonization scenario and electricity reaches a share of 59% in 2050 with a massive uptake of electric vehicles that substitute conventional ICEs in passenger and freight transport already in this critical decade. This increase of electricity along with the increased use of biofuels (especially in hard-to-electrify transport segments like aviation and shipping) would lead to a deep decarbonization of the transport sector with transport related emissions declining by 88% by 2050 from their 2015 levels. The use of more efficient vehicles (especially electric vehicles) leads also to an overall

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reduction of the final transport energy demand. The next Japanese NDC should have clear measures to accelerate the uptake of energy efficient and low-emission vehicles (e.g. electric vehicles) while behavioural and lifestyle changes should also be a key component of the overall climate strategy, as they reduce emissions at a very low cost and contribute to several Sustainable Development Goals.

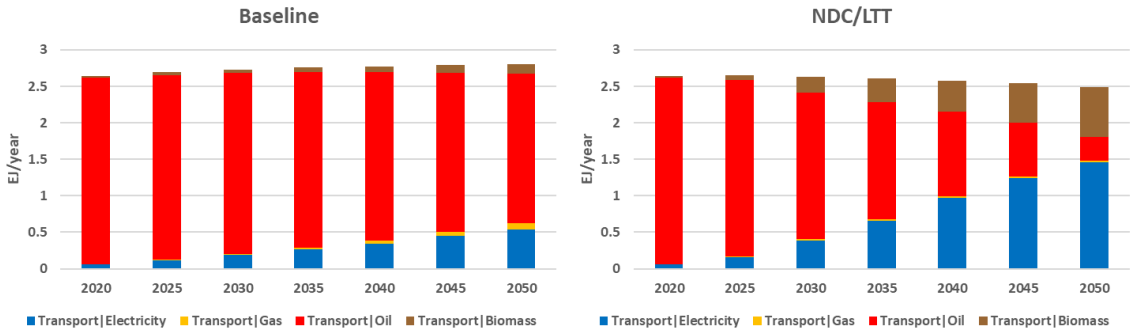

Figure 9: Final energy demand in the transport sector by fuel

Buildings

The final energy demand projections of the building sector for the Baseline and NDC/LTT scenarios are depicted in . In the business-as-usual scenario, the share of electricity further increases and reaches 67% in 2050 but the consumption of oil and gas remains significant by 2050, despite their declining shares. In the NDC/LTT scenario, the electrification of the building sector is stronger than in the baseline and electricity covers 88% of buildings energy needs in 2050 driven mostly by the increased deployment of heat pumps replacing oil and gas boilers for space heating. The high energy efficiency of heat pumps leads to a reduction of the overall final energy of buildings in the NDC/LTT scenario by more than 15% compared to the Baseline in 2050. In the decarbonization scenario, biomass has an increased share of 11% in 2050 and fossil fuels are nearly phased out in 2050 with a share of less than 1%. Strong climate policies lead to a complete decarbonization of the sector and in the NDC/LTT scenario CO2 emissions of the building sector are negligible in 2050.

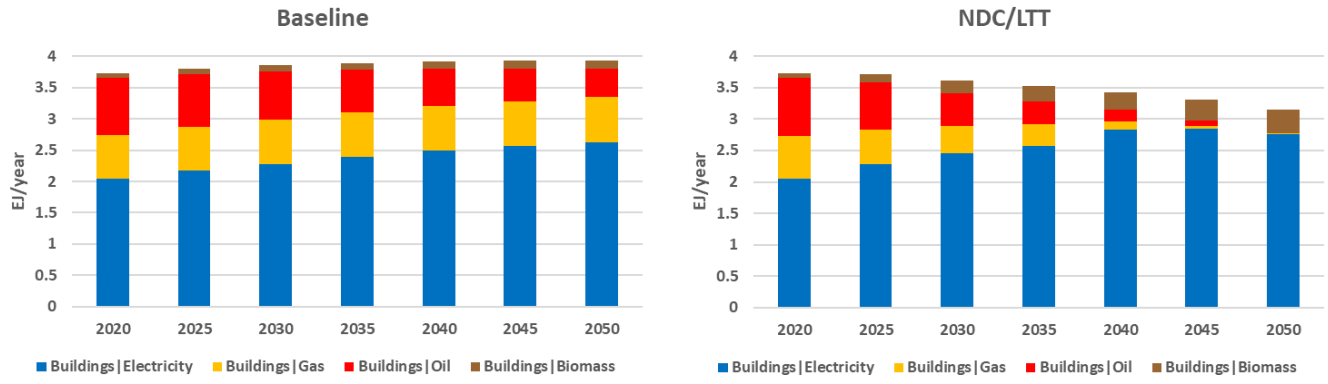

Figure 10. The Japanese building stock is already quite energy efficient compared with the world average, but there

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is room for further energy savings triggered by increasing the rate and deepness of building shell renovations and by inforncing more stringent energy building standards; these measures are assumed to accelerate in the NDC/LTT scenario leading to a large energy demand reduction compared to the Baseline. Electricity in commercial and residential sectors in Japan is the dominant fuel with a share of 54% in 2020 in the final energy mix of the sector followed by a strong presence of oil and gas, mainly for heating purposes. In the business-as-usual scenario, the share of electricity further increases and reaches 67% in 2050 but the consumption of oil and gas remains significant by 2050, despite their declining shares. In the NDC/LTT scenario, the electrification of the building sector is stronger than in the baseline and electricity covers 88% of buildings energy needs in 2050 driven mostly by the increased deployment of heat pumps replacing oil and gas boilers for space heating. The high energy efficiency of heat pumps leads to a reduction of the overall final energy of buildings in the NDC/LTT scenario by more than 15% compared to the Baseline in 2050. In the decarbonization scenario, biomass has an increased share of 11% in 2050 and fossil fuels are nearly phased out in 2050 with a share of less than 1%. Strong climate policies lead to a complete decarbonization of the sector and in the NDC/LTT scenario CO_2 emissions of the building sector are negligible in 2050.

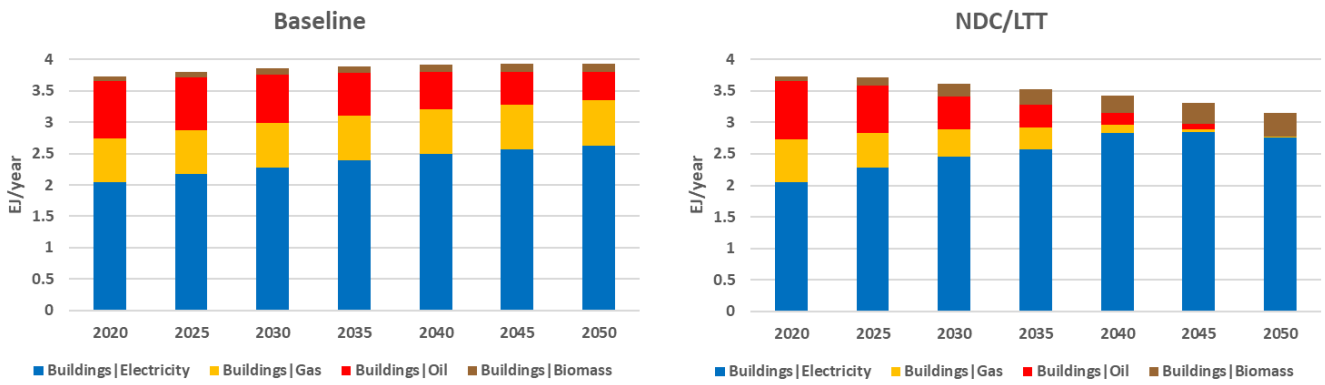

Figure 10: Final energy demand in the buildings sector by fuel

Electricity Production

The projected electricity production for the Baseline and decarbonization scenarios is shown in Figure 11. The generation of electricity in Japan in the period 2010-2020 was significantly reduced due to the Fukushima nuclear disaster in 2011 and the subsequent shut-down of nuclear generators; Japan produced 4 EJ in 2010 and 3.5 EJ in 2020. In both scenarios, electricity generation is projected to increase from 2020 levels driven by the increasing electrification trend. In the business-as-usual scenario, generated electricity in 2030 reaches 4 EJ (near pre-Fukushima levels) and increases further to 4.9 EJ in 2050. In the NDC/LTT scenario, the increased electrification of energy and transport uses leads to a more substantial growth than in the Baseline scenario and in 2030 generated electricity is projected to be 4.6 EJ and reaches 6.7 EJ in 2050, almost double the amount of the year 2020.

The power generation mix in the two scenarios differs. In the Baseline scenario, gas and coal-fired power plants are present in the power-mix even in 2050 and the share of fossil fuel-based generation is nearly 50% in 2030 and 22% in 2050. The presence of renewables becomes more prominent and renewable energy production (wind, solar, hydro, biomass) amounts to 62% of the overall electricity mix in 2050. Nuclear energy steadily recovers and in 2050 nuclear based electricity accounts for 15% of the power mix, however the quantity of nuclear production remains

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lower than in 2010 reflecting the shut-down of older nuclear plants. In the NDC/LTT scenario, the increase of electricity production is supplemented with the extensive development of low-carbon technologies and the rapid phase out of fossil fuels. Coal and oil-based power plants are projected to be discontinued by 2040, while in 2050 the use of unabated gas in electricity production is nearly eliminated as well. Renewables and particularly solar power have a dominant role in the electricity mix; in 2050 production from renewables (wind onshore and offshore, solar, hydro, biomass) amounts to more than 70% of overall generation and solar power alone represents 37% of Japan's electricity generation, while wind onshore deployment is limited by Japan's wind resource potentials. In the NDC/LTT scenario, the recovery of nuclear-based electricity is more prominent than in the Baseline scenario and nuclear energy is projected to reach 2010 levels in 2035 (~1 EJ) and in 2050 increases to 1.35 EJ and constitutes 20% of overall generated electricity as the limited RES potentials require a further expansion of nuclear power to ensure a decarbonised power grid before 2050. However, the revival and expansion of nuclear power in Japan faces important societal, political, environmental and financial challenges, especially after the Fukushima accident. In 2050, the remaining 10% of electricity is produced by gas and 80% of the gas-based generation is combined with CCS technologies, enabling the almost complete decarbonization of the power sector in the NDC/LTT scenario. The emergence of CCS technologies is an important part of Japan's climate strategy towards net-zero by 2050, but the actual implementation of such projects faces significant socio-political, environmental and economic challenges and should be actively embedded in the overall transition strategy, with CCS technology applications both in power generation and in industrial processes.

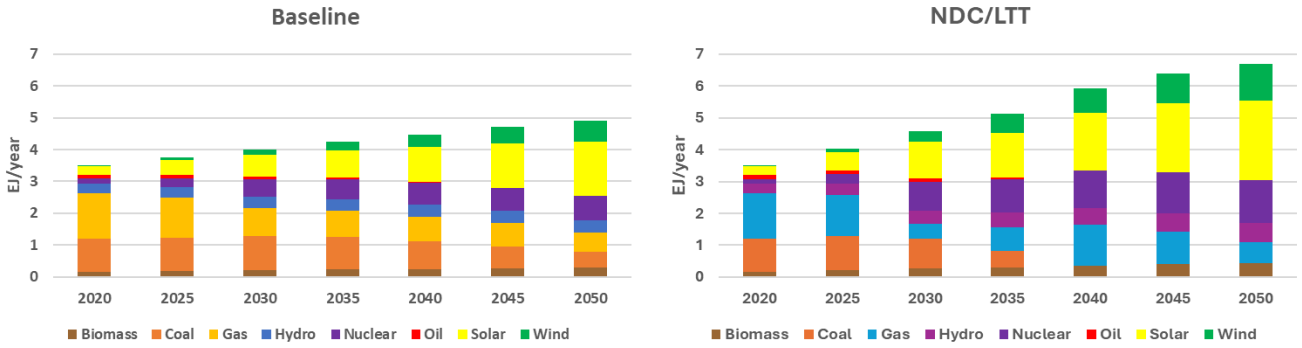

Figure 11: Electricity production in Japan by fuel in the Baseline and decarbonization scenarios

Key messages for next NDCs

Japan revised its initial NDC target of reducing economy-wide GHG emissions by 26% by 2030, to a more ambitious goal of reducing GHG emissions by 46% compared to the national GHG emissions of 2013, the year that marked Japan's peak emissions in the aftermath of the Fukushima disaster. The current NDC target for 2030 is aligned with Japan's long-term target (LTT) and the commitment of achieving carbon neutrality by 2050. However, Japan has only reduced its emissions by 17% in the last decade, indicating a relatively slow progress in its climate efforts and the need to establish more ambitious climate policies to ensure the achievement of its NDC targets for 2030. As a large share of these emissions reductions come from the revival of nuclear power plants (that were shut down after the Fukushima accident) and the subsequent drop in fossil-fired power generation, significant challenges remain to make the necessary transformative changes to reduce the use of fossil fuels in all sectors of the economy.

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The energy sector plays a crucial role in Japan's economy and societal well-being, as it underpins industrial activity, transportation, and residential needs, driving the nation's economic growth and stability. The power sector is pivotal, and its transformation based on renewable energy uptake is key to achieve Japan's NDC commitments and the target of net-zero emissions by 2050. Achieving the country's climate targets, however, requires significant decarbonization efforts also in demand sectors and specifically in the industrial and transportation sectors. Emission reduction efforts in these sectors should be prioritized as part of Japan's new NDC with specific measures to ensure the cost-efficient and just transformation of these sectors in the next decade paving the way towards climate neutrality by mid-century. A decarbonization pathway needs significant investments in renewable energy, energy efficiency, and innovative technologies (e.g. hydrogen for steelmaking, Carbon Capture and Storage applied both in industrial processes and in electricity production) to create a sustainable and resilient energy system and requires deep electrification of energy demand combined with an accelerated uptake of renewable energy sources in all sectors.

References

[1] https://worldpopulationreview.com/

[2] https://www.worlddata.info/

[3] https://www.worldeconomics.com/

[4] https://www.worldbank.org/

[5] https://www.statista.com/statistics/270093/distribution-of-gross-domestic-product-gdp-across-economic-sectors-in-japan/

[6] https://edgar.jrc.ec.europa.eu/report_2023

[7] https://www.climatewatchdata.org/

[8] https://unfccc.int/sites/default/files/NDC/2022-06/JAPAN_FIRST%20NDC%20%28INTERIM-UPDATED%20SUBMISSION%29.pdf

[9] Fragkos, P. et al (2013). Model-based analysis of the future strategies for the MENA energy system. Energy Strategy Reviews.

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COUNTRY REPORT

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