Chapter 7

Japan Country Report

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1. Basic Concept of Low-carbon Energy Transition – Carbon Neutrality

Introduction

In October 2020, the Government of Japan declared the target of carbon neutrality by 2050. After that, in 2021, the government updated its nationally determined contribution (NDC) for 2030 to 46% below the 2013 greenhouse gas (GHG) emissions. The government previously declared the emissions target of just 26% below the 2013 level, and the target has been replaced by a far more ambitious one.

The 6th Strategic Energy Plan (METI, 2021a), approved by the Cabinet in 2021, the same year as the NDC update, outlines these quantitative targets and the actions to be taken in each energy sector for carbon neutrality by 2050 and the NDC for 2030.

Whilst Japan is aiming to materialise carbon neutrality, the current energy mix in the country is heavily dependent on fossil fuels. In 2020, fossil fuels made up 85% of primary energy supply (METI, 2021b). Power generation is a relatively decarbonised sector, but generation from coal, oil, and natural gas still covers 74% of total power generation. Japan has to substitute this fossil fuel demand or capture and store the emissions as much as that from fossil fuels in order to neutralise GHG emissions.

To consider energy supply and demand in Japan, this report presents the business as usual (BAU) scenario in which similar energy policies are currently taken, an alternative policy (AP) scenario in which further powerful measures for climate issues are taken from there (these two are forecast scenarios), and the low-carbon energy transition–carbon neutral (LCET–CN) scenario, a back-cast scenario for carbon neutrality. This scenario analysis will show the difference between Japan's carbon neutrality and the forecast scenarios and summarises the challenges to achieving it.

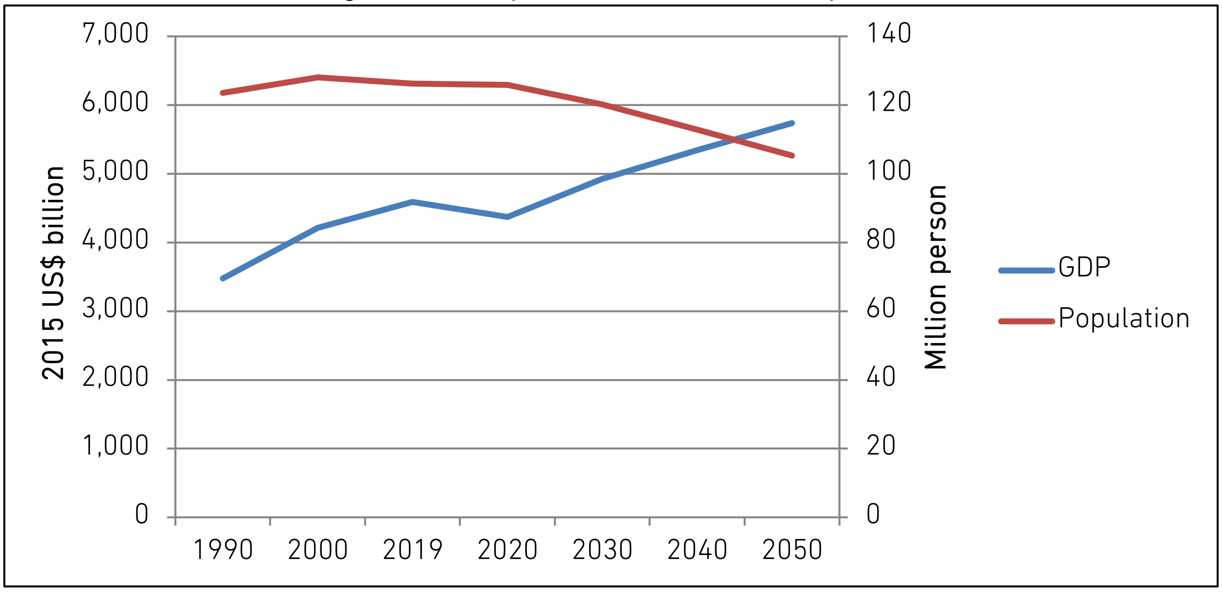
2. Modelling Assumptions

Macroeconomy

The general assumption for the macroeconomy is as described in ERIA (2023). Recently, Japan's gross domestic product (GDP) has continued to moderate and has achieved steady growth at 1.0% per year between 2010 and 2019. On the other hand, in 2020, the GDP declined 4.8% from the previous year due to the economic damage from the novel coronavirus disease (COVID-19) pandemic. In this outlook, the economy is projected to restart a slow and steady growth so that the GDP is assumed to grow at an average annual rate of 0.8% in the outlook period (from 2021 to 2050).

The population in Japan peaked around 2010 and has been declining since then. In the outlook period, the population will decline by about 0.6% per year due to the low birth rate. Consequently, the population is projected to decline from 126 million in 2020 to 105 million in 2050. Figure 7.1 shows the assumptions of GDP and population in this outlook.

Figure 7.1. Population and GDP Prospects



GDP = gross domestic product.

Sources: GDP: IMF (2021) and authors; population: UN DESA (2019).

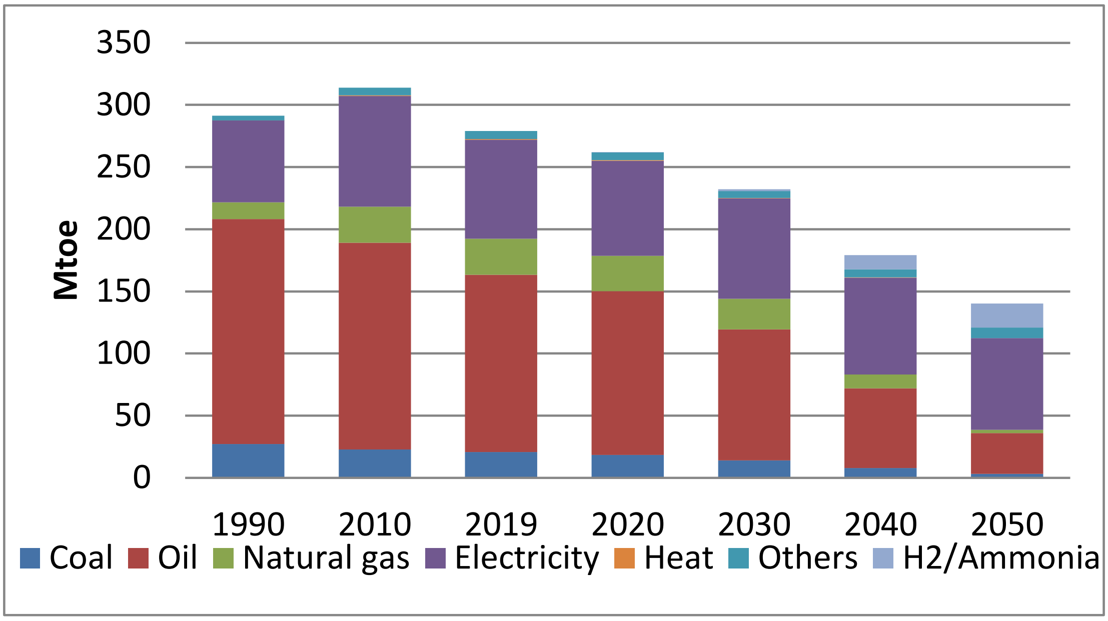
Additionally, the LCET–CN scenario is a back-casting scenario that assumes carbon neutrality in 2050. In the scenario, necessary efforts to achieve it will be made (regardless of cost efficiency). Since Japan has a very limited carbon capture and storage (CCS) potential, it is hardly considered in the BAU and the AP scenarios. However, the LCET–CN scenario assumes CCS penetration into existing thermal power plants and industrial processes due to the need for carbon neutrality.

3. Final Energy Consumption

In the LCET–CN scenario, the final energy consumption will decline approximately 2.5 times faster than in the BAU scenario, falling to 140 million tonnes of oil equivalent (Mtoe) in 2050 (Figure 7.2). The demand is equivalent to 64% of the BAU level.

To achieve carbon neutrality, significant energy transition from fossil fuels to electricity and hydrogen must be made. The fossil-fuel share will decrease drastically, from 69% of energy in 2019 to 27% in 2050. On the other hand, the share of electricity will increase from 29% in 2019 to 52% in 2050. Hydrogen and ammonia consumption starts in 2030 and finally made up 15% of final consumption in 2050.

Figure 7.1. Final Energy Consumption by Source

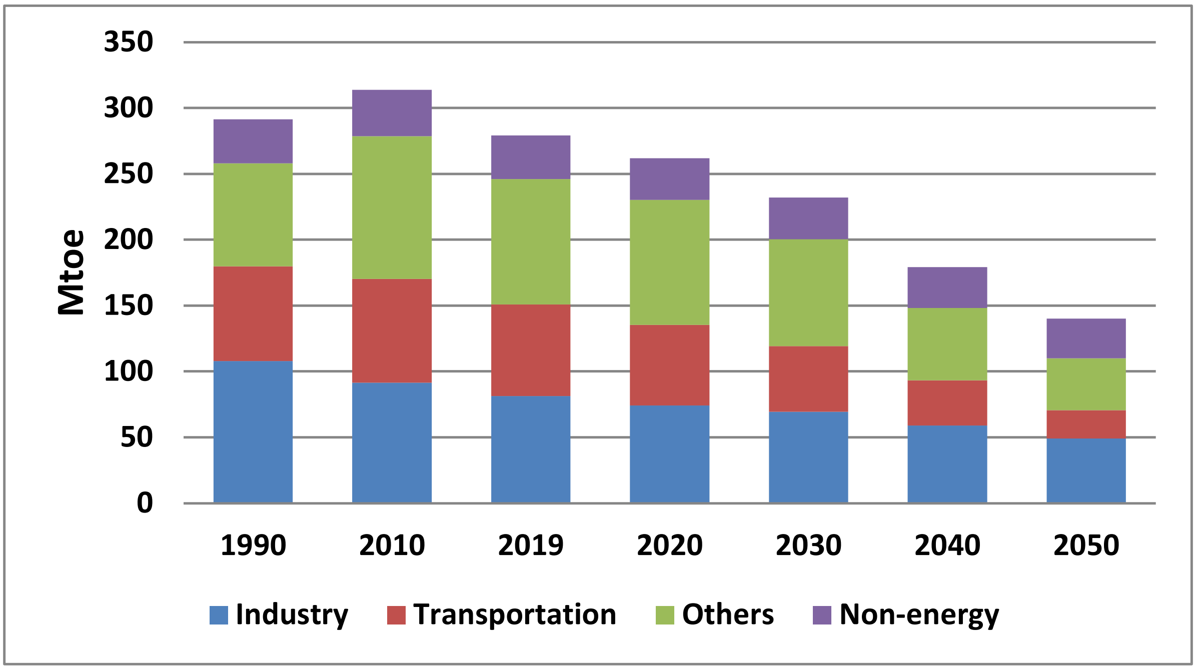


H_2 = hydrogen, Mtoe = million tonnes of oil equivalent.

Source: Authors' calculation.

In the transport and 'others' (residential and service) sectors, demand will be greatly reduced due to intensive energy conservation effort and electrification, which will improve energy efficiency (Figure 7.3). In the transport sector, higher efficiency of electric vehicles and fuel cell vehicles will largely contribute to drastic energy conservation. In the 'others' sector, electrification will significantly progress. In the industry sector, on the other hand, the decline will be limited. In this sector, it will be difficult to substitute all the fossil-fuel demand to electricity or hydrogen, due to the need for high-temperature heat sources and lock-in effect of existing machinery. Instead, CCS is assumed to implement to reduce CO_2 emissions.

Figure 7.3. Final Energy Consumption by Sector



Mtoe = million tonnes of oil equivalent.

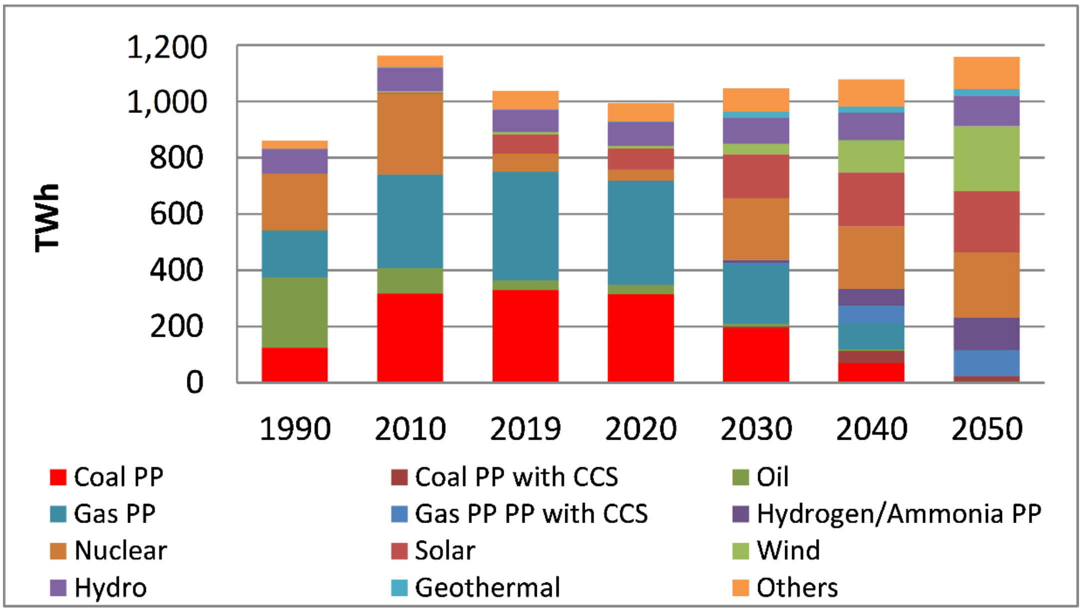
Source: Authors' calculation.

4. Power Generation

Power generation for the LCET–CN scenario in 2050 is projected to be 1,178 terawatt-hours (TWh). Due to rapid progress of electrification and demand for green hydrogen, generation for the LCET–CN scenario in 2050 will be larger than that in 2019, whilst total energy supply will decrease from that of 2019.

About 39% will be from solar photovoltaic (PV) and wind power. Since output from these variable renewable energies is unstable, backup storage and expansion of the grid will be necessary. Other renewables (hydro, geothermal, and biomass) will account for 21%. Nuclear energy covers 20% of total generation. The remaining 20% is thermal power, of which another 10% is hydrogen and 10% is coal and natural gas with CCS.

Figure 7.4. Power Generation, BAU, AP, and LCET–CN Scenarios



AP = alternative policy, BAU = business as usual, CCS = carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral, PP = power plant, TWh = terawatt-hour.

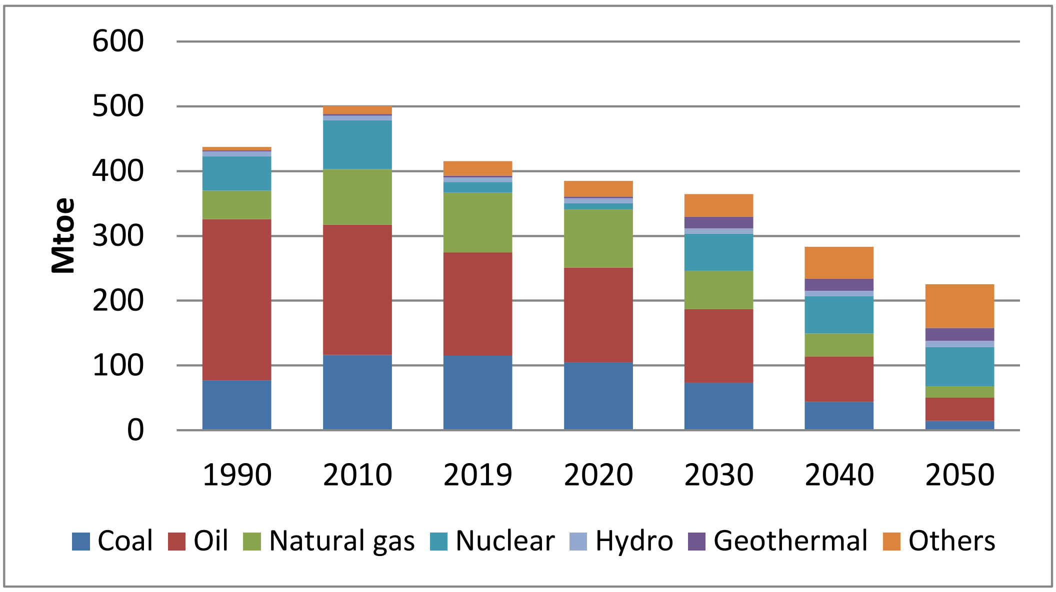
Source: Authors' calculation.

5. Primary Energy Supply

In the LCET–CN scenario, the primary energy supply will decline as significantly as final energy demand declines; the primary supply in 2050 is projected to be 247 Mtoe, 73% of the BAU level (Figure 7.5).

In addition, the share of fossil fuels, which accounted for 88% of the primary energy supply in Japan in 2019, will shrink to 28% in 2050. Nevertheless, even in such a progressively decarbonised scenario, demands for fossil fuels will not disappear, and efforts for stable supply of fossil fuels will remain one of the key energy policies in Japan.

Figure 7.5. Primary Energy Supply, BAU, AP, and LCET–CN Scenarios



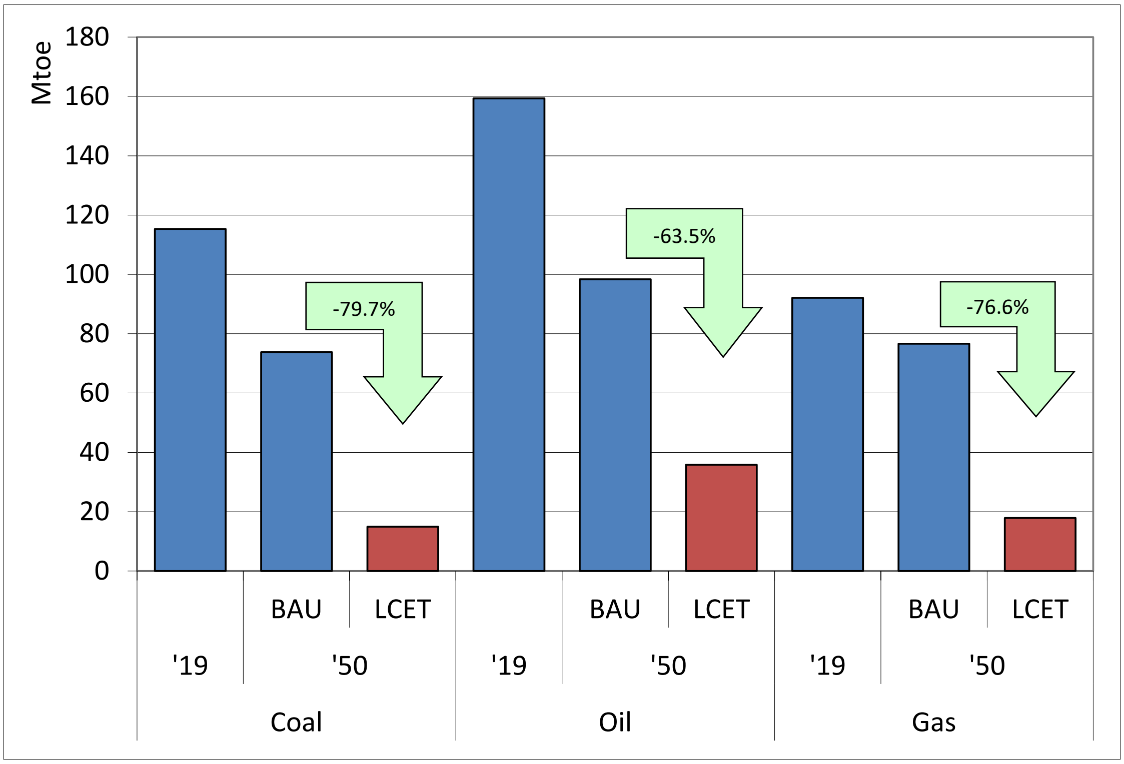
AP = alternative policy, BAU = business as usual, CCS = carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.

Source: Authors' calculation.

6. Saving of Fossil Fuel Consumption and CO_2 Reduction

In the LCET–CN scenario, fossil fuel consumption will be about 25% of the BAU scenario, which will reduce 188 Mtoe (Figure 7.6). Amongst fossil fuels, coal is mostly replaced by other energy sources in industry and power sectors, with demand of only 15 Mtoe in 2050. On the other hand, oil demand will linger relatively even in 2050, which is used mainly in the industry and non-energy sectors.

Figure 7.6. Fossil Fuel Reduction in Primary Energy Supply, BAU, APS, and LCET–CN Scenarios

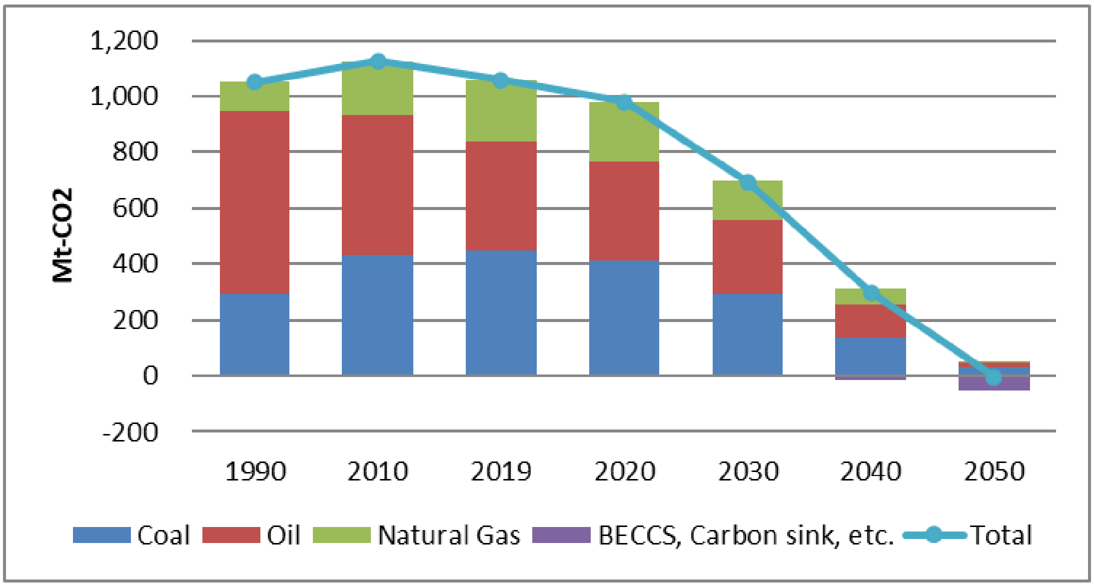


AP = alternative policy, BAU = business as usual, CCS = carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral, Mt-CO_2 = metric million tonnes of carbon.

Source: Authors' calculation.

Emissions in the LCET–CN scenario show even faster reductions than the trend (Figure 7.7). Japan's NDC target of energy-related CO_2 emissions for 2030 is 185 million tons of carbon (Mt-C), a 45% reduction from the 2013 level. The LCET–CN scenario will be consistent with the NDC target. In 2050, there are small fossil fuel demands that are difficult to substitute to a carbon-free energy source, leaving about 15 Mt-C of emissions from coal and oil. The residual emissions will be offset by negative emissions such as biomass CCS and forestry to achieve carbon neutrality.

Figure 7.7. Carbon Dioxide Emissions from Fossil Fuel Combustion, BAU, AP, and LCET–CN Scenarios



AP = alternative policy, BAU = business as usual, BECCS = bioenergy with carbon capture and storage, CCS = carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral, Mt-CO_2 = metric million tonnes of carbon.

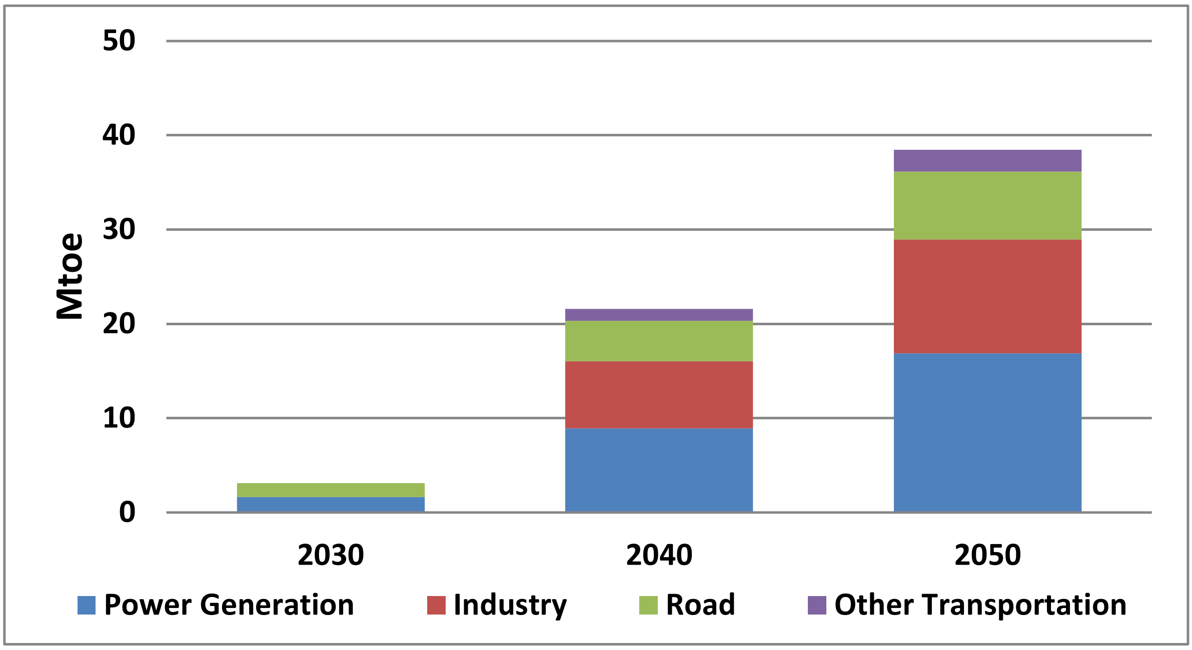
Source: Authors' calculation.

7. Hydrogen Demand across the Sector

In 2030, hydrogen consumption will be limited. Mainly it will be used as fuel for ammonia co-firing in coal-fired power plants and for hydrogen fuel cell vehicles. After 2040, hydrogen will also be used for industrial heating and as a fuel for other transportation (ships).

Consumption in 2050 will be about 40 Mtoe, which will account for 15% of final consumption.

Figure 7.8. Hydrogen Demand



Mtoe = million tonnes of oil equivalent.

Source: Authors' calculation.

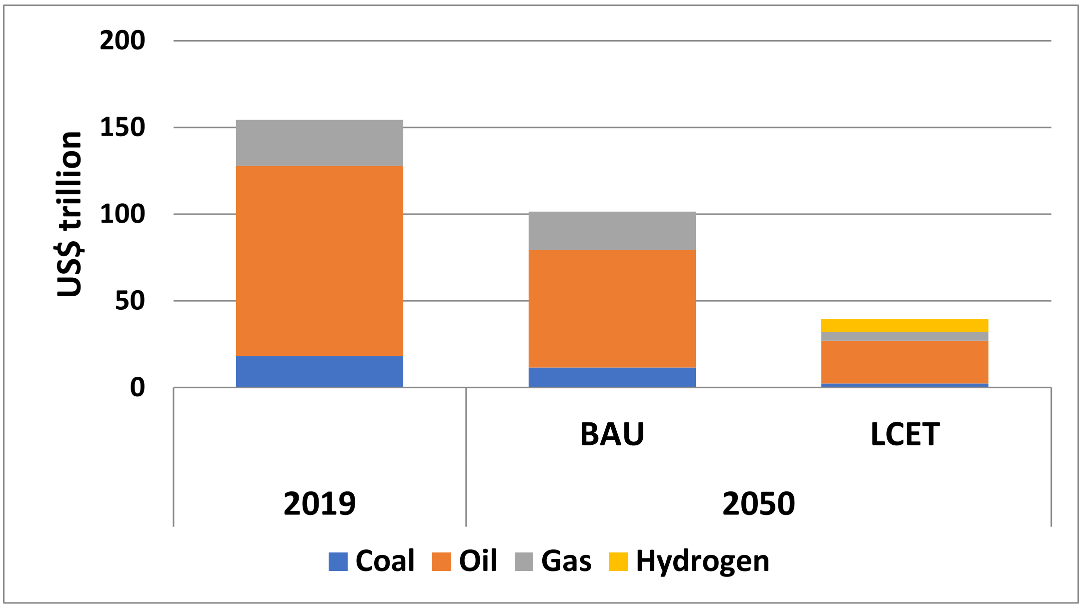
8. Energy Cost Comparison between BAU and LCET–CN Scenarios

In order to evaluate the cost of energy transition, key energy-related costs (fuel, investment for power generation, and CCS) for BAU and LCET–CN scenarios are evaluated based on the outlook results. In this sector, the US dollar means the real price in 2020.

8.1. Fuel Costs

Fuel costs in 2050 are US$39 trillion in the LCET–CN scenario because fossil fuel demand is much lower than in the BAU scenario. Although LCET–CN incurs additional costs due to hydrogen, the total fuel cost is still about 40% of the BAU scenario. We note, however, that this is a cost assessment based on ambitious assumptions regarding hydrogen and ammonia cost reductions, and the total cost may vary depending on the technology progress.

Figure 7.9. Fuel Cost



BAU = business as usual, LCET = low-carbon energy transition.

Note: 'Hydrogen' is only the cost of imported hydrogen and does not include the cost of green hydrogen to avoid double counting with the cost of power generation investment.

Source: Authors' calculation.

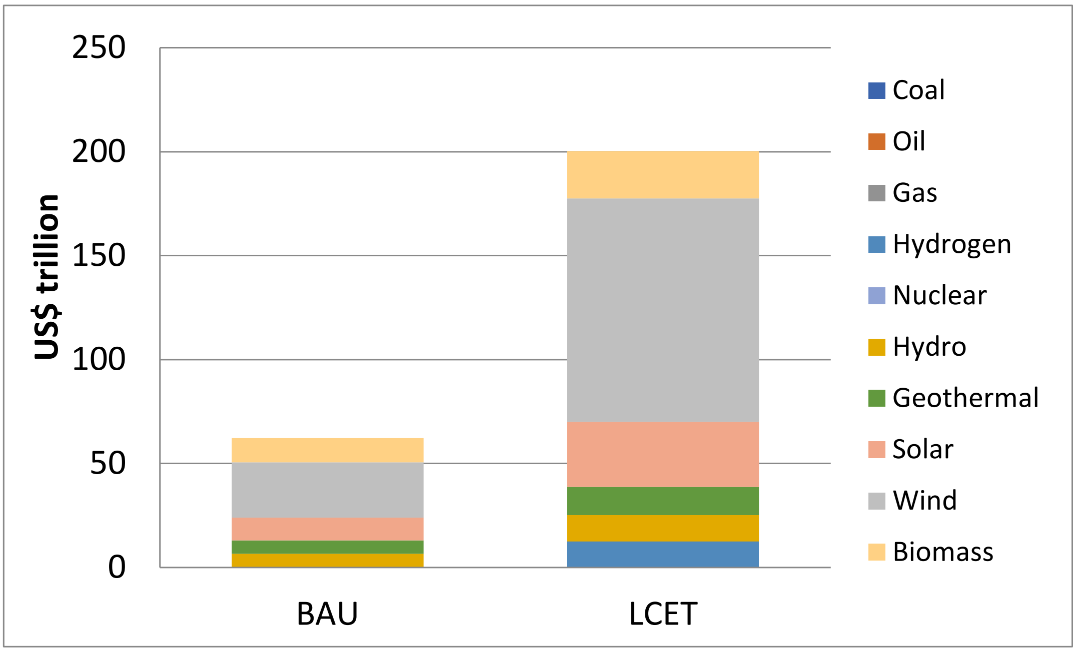
8.2. Power Generation Investment

To estimate the cost of investing in power generation equipment, the unit cost for each power was multiplied by the increase in installed capacity by 2050.

The LCET–CN scenario requires a capital cost of power generation (cumulative from 2020 to 2050) of US$200 trillion, which is more than three times that in the BAU scenario. Especially, large investments are required for solar PV and wind power.

The amount of power generation required in the LCET–CN scenario is 13% larger than that in BAU, so more capital investment is needed to accommodate the additional generation.

Figure 7.10. Power Generation Investment



BAU = business as usual, LCET = low-carbon energy transition.

Source: Authors' calculation.

8.3. CCS Cost

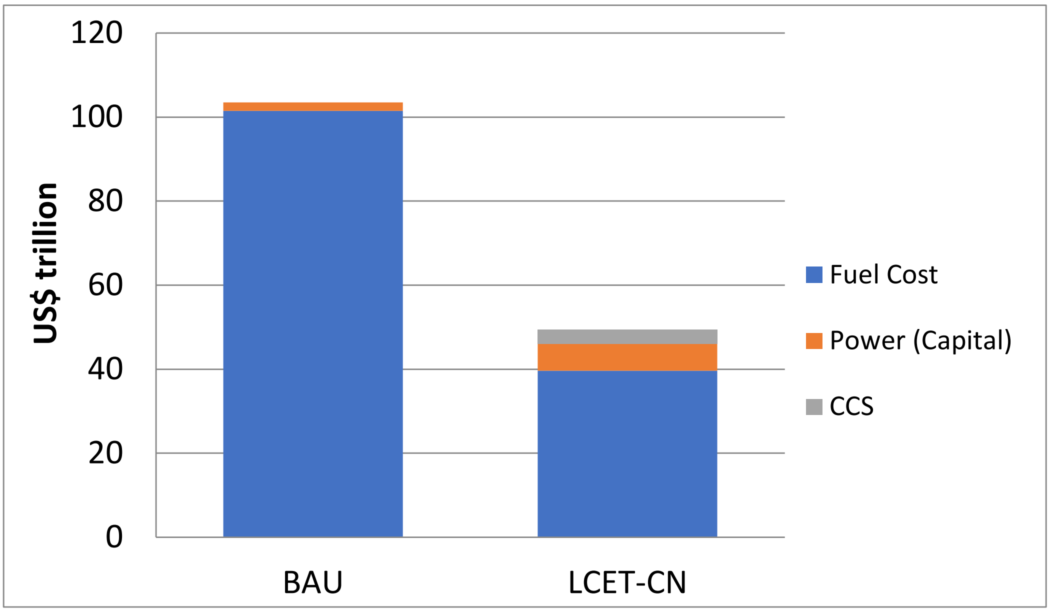
This cost element includes those for CCS implementation into power generation (gas and coal-fired).

The BAU scenario does not consider CCS, so its cost is zero. The LCET-CN scenario assumes that CCS will be incorporated into all coal-fired and gas-fired power plants and is estimated to cost US$3.4 trillion for its capture and storage.

8.4. Overall Cost

So far, costs related to fuels, generation capacities, and CCS have been evaluated. The total in 2050 are shown in Figure 7.11.

Figure 7.11. Cost in BAU and LCET–CN, 2050



BAU = business as usual, CCS = carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral.

Notes: All of the costs are converted to an annual basis. This cost evaluation does not include those for energy efficiency improvement, energy storage, distribution, and transmission.

Source: Authors' calculation.

Due to the significant reduction in fuel costs, the cost of the LCET–CN scenario is less than half that of the BAU. Note, however, that this result does not necessarily imply that the cost of carbon neutrality is small.

Importantly, the LCET–CN scenario has significantly reduced energy demand due to energy efficiency improvement and this cost assessment does not include the costs for the efficiency improvement. Such costs vary greatly making them difficult to accurately evaluate them. However, as a rough evaluation, energy savings would cost at least about US$400 per kilolitre oil equivalent as of 2015 (METI, 2015). Furthermore, this cost per unit of energy saved will rise more and more with each increase in energy saved, so this can be a significant additional cost element of the LCET–CN scenario.

9. Conclusions and Policy Recommendations

According to Japan's net-zero policy, energy demand and CO_2 emissions can be reduced, however, net-zero emissions will not be materialised in the BAU and the AP scenarios. In the BAU scenario, CO_2 emissions in 2050 are 65% of 2019 levels. The AP scenario assumes faster energy efficiency improvements than the current trend, progress in restart of nuclear power plants and massive introduction of renewable energy so that CO_2 emissions in 2050 will be reduced to 41% of the 2019 level. Although this is a decent improvement, the results are still far from carbon neutral. They indicate that carbon neutrality requires further CO_2 reduction efforts than assumed in the forecast scenarios such as the BAU and the AP scenarios. In contrast, the LCET–CN scenario will complement this concern, which is a back-casting scenario that assumes carbon neutrality in 2050, as defined.

Nonetheless, CO_2 reduction is not the only focal point of energy policy. '3E+S' (Environment, Energy Security, Economic Efficiency + Safety) is a fundamental –principle in Japan's energy policy. Whilst the LCET–CN is a scenario that pursues environment, the scenario shows some challenges in terms of the remaining other two Es: energy security and economic efficiency.

(i) Energy Security

- Fossil fuels will be reduced to 32% of primary supply in the LCET–CN scenario but remain a necessary energy source. Efforts for a stable supply, from upstream investments to downstream infrastructure maintenance, will be still essential.
- Electricity and hydrogen will be largely deployed to replace fossil fuels. Challenges for energy security for these energies are also inevitable.
  - Electricity must be supplied stably, in greater quantities than at present, and without CO_2 emissions. In the LCET–CN scenario, the amount of power generation in 2050 is about 8% greater than today. Japan's government has already set renewable energy as its main power source. It is essential to develop the dispatchable capacity and adjust the capability for output fluctuation of renewables. Currently, investment in thermal power generation to provide this adjustment is difficult due to volatile wholesale electricity prices and decarbonisation policies, but policy efforts must continue to ensure sufficient capacity through 2050 and in the interim.
  - Hydrogen is expected to be supplied mainly through water electrolysis and imports in Japan, which has scarce fossil-fuel resources. Efforts must be made to build good relationships with hydrogen supplier countries and to form an international market, in the same way Japan currently does for a stable supply of fossil fuels.

- On the other hand, efforts towards carbon neutrality will increase the energy self-sufficiency rate. It will improve from 15% in 2020 to 65% in 2050 under the LCET–CN scenario.

(ii) Economic Efficiency

- Energy costs are also a significant issue. Although the costs of solar PV and wind power, which account for a significant share of electricity, are declining, additional costs will arise for investments in batteries to regulate their output, transmission lines to power generation facilities, and so on. In general, as the variable renewable energies share increases, the cost per kilowatt hour itself increases cumulatively. Therefore, it is necessary to try to utilise other power sources such as nuclear, hydrogen, and fossil fuels with CCS to reduce costs, rather than relying too heavily on renewable energy.

- In addition, the costs of energy efficiency improvement are expected to be enormous. The cost evaluation showed that efforts toward carbon neutrality can lead to reducing fuel and power generation costs. It should be noted, however, that the evaluation does not fully evaluate the costs associated with energy conservation (e.g. from installing high-efficiency equipment or changing operations).

Carbon neutrality is exceedingly difficult to achieve with a combination of existing and mature technologies, and the LCET–CN scenario incorporates developing technologies such as CCS and hydrogen. Financial and technical support from the government for these technologies are significant. In addition, in the transition period around 2040, current technologies and facilities will be mixed with these developing technologies including hydrogen and CCS. It is essential to replace existing technologies with new technologies prudently so that a stable energy supply will not be compromised in the process.

References

Economic Research Institute of East Asia (ERIA) (2023), *Energy Outlook and Energy Saving Potential in East Asia 2023.* Jakarta: ERIA. https://www.eria.org/publications/energy-outlook-and-energy-saving-potential-in-east-asia-2023/ (accessed December 2023).

International Monetary Fund (IMF) (2021), *World Economic Outlook October 2021. Recovery during a Pandemic.* Washington, DC: IMF. https://www.imf.org/en/Publications/WEO/Issues/2021/10/12/world-economic-outlook-october-2021 (accessed July 2023).

Ministry of Economy, Trade and Industry Japan (METI) (2015), 'Relationship Between Energy Saving Effect and Investment'. https://www.meti.go.jp/shingikai/enecho/shoene_shinene/sho_energy/pdf/012_02_00.pdf (accessed July 2023). (in Japanese)

Ministry of Economy, Trade and Industry Japan (METI) (2021a), Strategic Energy Plan. https://www.enecho.meti.go.jp/en/category/others/basic_plan/ (accessed July 2023).

Ministry of Economy, Trade and Industry Japan (METI) (2021b), Energy Balance Table. https://www.enecho.meti.go.jp/statistics/total_energy/ (accessed July 2023).

United Nations Department of Economic and Social Affairs. Population Division (UN DESA) (2019), *World Population Prospects 2019*. New York: United Nations. https://population.un.org/wpp/ (accessed November 2021).