Japan's Quantitative Emission Scenario of GHG Net Zero and its Implications for Asian Countries

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Abstract

Japan enacted legislation in 2021 incorporating the aim of achieving net zero greenhouse gas (GHG) emissions by 2050 based on temperature targets set in the Paris Agreement. Our research attempted to quantitatively express the combination of technologies, energy supply and demand, and structure of GHG emissions required to achieve net zero GHG emissions by 2050. The combination of measures necessary to achieve this goal was estimated by using a computable general equilibrium model, a technology selection model and an optimal generation planning model while considering factors including the consistency of the future economy and energy demand, feasible technology deployment speed and the maintenance of regional and temporal balances for electricity demand and supply. The results show that major changes in the energy system will be necessary, including shifting from fossil fuel to electricity, expanding the use of hydrogen and hydrogen-based fuels, and expanding the use of renewable energy. Also, negative emission measures will be required to address residual emissions. In addition, reducing energy demand through social transformation was shown to reduce dependence on measures the efficacy of which is highly uncertain and thereby increase the possibility of achieving net zero GHG emissions. These findings are also applicable to building a decarbonized society in Asian countries, while taking into account each country's stage of development and taking advantage of climatic and regional characteristics.

Key words: computable general equilibrium model, decarbonized society, net zero GHG emissions, optimal generation planning model, renewable energy, technology selection model

1. Introduction

At the start of the 2010s, Japan's greenhouse gas (GHG) emissions rose due to the impact of the nuclear power plant accident caused by the Great East Japan Earthquake. However, since peaking in FY2013 at 1.41Gt-CO_2eq, emissions have decreased for six consecutive years, with emissions in FY2020 (1.15Gt-CO_2eq) being 18.4% less than emissions in 2013 (Fig. 1). CO_2 accounted for more than 90% of GHG emissions in FY2020 (84% energy-related CO_2, 7% non-energy related CO_2), while methane and N_2O each accounted for 2%, and four other gases including CFC alternatives accounted for 5% (NIES, 2022).

Japan's GHG emission reduction target as pledged in the INDC (Intended Nationally Determined Contributions) submitted to the United Nations

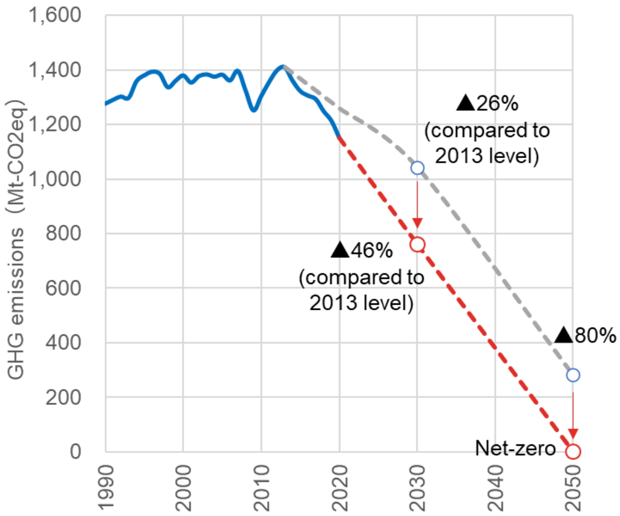

Fig. 1 Japan's GHG emissions and reduction targets.

Framework Convention on Climate Change (UNFCCC) Secretariat in 2015 and the NDC (Nationally Determined Contributions) submitted in March 2020 was a 26% reduction in FY2030 relative to emissions in FY2013. In addition, the target for 2050 in the long-term strategy submitted to the UNFCCC Secretariat in June 2019 was an 80% reduction. In October 2020, then Prime Minister Suga declared that Japan would aim to achieve carbon neutrality by 2050. This was followed by an amendment of the Act on Promotion of Global Warming Countermeasures to incorporate net zero GHG emissions by 2050 as a target. In addition, after a meeting of the Global Warming Prevention Headquarters, Prime Minister Suga stated that Japan would seek a 46% reduction in emissions by 2030 and would continue to aim to cut emissions by 50%. A subsequent internal review by the government led to the formulation of a plan consistent with these targets and approval by the Cabinet of a revised Plan for Global Warming Countermeasures on October 22, 2021. The revised NDC incorporating the targets and long-term strategy was resubmitted to the UNFCC Secretariat. Japan had finally made a start toward achieving net zero GHG emissions.

However, the process of compiling the necessary combination of substantive countermeasures and policies to achieve the new ambitious target of 46% reduction by 2030 has been extremely difficult. The government's plan for 2050 does not set forth a list of necessary substantive countermeasures.

Our analysis used the three models described in the next section to estimate the combination of measures required to achieve net zero GHG emissions in 2050 with the goal of providing information that will contribute to realizing a decarbonized society in Japan.

Currently, 133 countries around the world have declared net zero emission goals (Net Zero Tracker, as of December 26, 2022), and in Asia, major countries such as China, India, Indonesia, South Korea, Malaysia, Thailand and Vietnam have all declared net zero emission goals. In this context, we also describe the implications of the findings from our analysis of Japan for the decarbonization of societies in Asian countries.

The analysis of Japan in this paper is based on the work presented in Hibino et al. (2022, in Japanese), and adds suggestions for a decarbonized society in Asia derived from the Japanese analysis.

2. Methods

2.1 Analytical Models

The three models shown in Fig. 2 were used in this analysis.

A recursive dynamic computable general equilibrium model for Japan (AIM/CGE) was used to estimate the future volume of services. AIM/CGE quantitatively projects future economic activity based on the assumptions for future economic outlooks by using the pricing mechanism to ensure consistency in the interrelationships of the economy as a whole. The economic activity in each sector was estimated based on the production value of goods and services estimated by the model. The results were used to estimate future

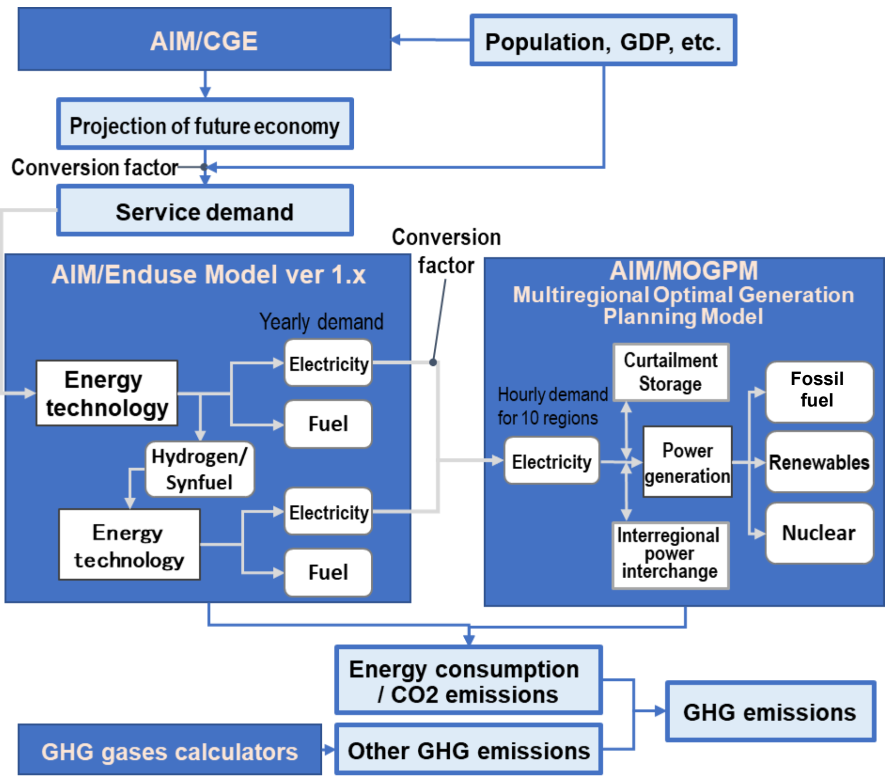

Fig. 2 Models used in the analysis.

service volumes such as material production, commercial floor space, and freight transportation for the final energy consumption sector. Details of AIM/CGE are described in Masui (2005).

Next, the technology selection model AIM/Enduse (v1.0) was used to estimate future energy demand. The AIM/Enduse model selects the energy equipment that minimizes costs for each year while satisfying the requirements for the exogenously input service volumes. Energy consumption is estimated by summing the technology for each service type by sector for Japan until 2050. Since the amount of technology replacement is calculated taking into account the technology's vintage, the rate of new technology introduction reflects the life span of the technology. Details of AIM/Enduse (V1.0) are described in Kainuma et al. (2003).

The AIM/Multiregional Optimal Generation Planning Model (AIM/MOGPM) was applied to the power sector to estimate a generation mix. This model can analyze the hourly electricity demand-supply balance including the inter-regional power interchange and storage input-output each of the 10 regions set based on the jurisdiction area of the electric power companies (EPCOs) such as Tokyo Electric Power Company (TEPCO) under the cost minimization condition. The model estimates a generation mix and primary energy consumption required for generation considering capital costs, operation and maintenance costs and fuel costs as well as the cost of electricity storage, cost of expansion of interconnection transmission lines, and curtailment of renewable energy output (amount of disconnection). The electricity demand used in the model is set based on results from the technology selection model. Details of AIM/MOGPM are described in Gao and Ashina (2022).

The total energy supply and demand for Japan and the corresponding CO_2 emissions were calculated by using the energy consumption for power generation estimated by AIM/MOGPM and the energy consumption for uses other than power generation estimated by AIM/Enduse. For GHG emissions other than energy-related CO_2, current emission rates and estimated reduction rates due to countermeasures were calculated for each gas and emission source, and the quantity of reductions and emissions were calculated by multiplying the two.

2.2 Analytical Framework

(1) Assumptions regarding Future Society and the Economy

For future GDP assumptions, a GDP growth rate up to 2030 of 1.7%/year is taken from the growth realization case in Cabinet Office (2021). GDP growth of 0.5%/year after 2030 is taken from the SSP2 scenario for the projected Japanese GDP rate from the IIASA SSP (Shared Socioeconomic Pathways) database (IIASA, 2018). Projected populations are taken from the medium-fertility/medium-mortality case of the National Institute of Population and Social Security Research (2017).

Future production volumes for materials and machinery products in the industrial sector were calculated from the production values by industry estimated by AIM/CGE based on the above assumptions for GDP. Commercial floorspace was calculated based on the purpose of buildings; for example, the floorspace for office buildings was estimated based on the number of employees; that for commercial facilities, on the production volume of commercial and personal services; and that for hospitals and schools, on the population composition. Passenger transportation was calculated from the future total population while freight transportation was calculated based on the current transportation volume for goods and future production values. The data for main activities are shown in Table 1.

(2) Reduction Measures

There are four main pillars for reducing energy-related CO_2 emissions to realize a decarbonized society: 1) reduction of demand for energy services, 2) improvement of energy efficiency, 3) promotion of electrification, and 4) decarbonization of energy production. For each of these pillars, a detailed list of countermeasure technologies was developed for each sector (Table 2). Measures to address GHG emissions other than energy-related CO_2 are listed in Table 3.

The model endogenously selects economical countermeasure technologies by considering fixed and variable costs including energy costs. Future cost reductions are anticipated for some technologies. Forecasts by IRENA (2019) were used for solar photovoltaic and wind power generation while forecasts by the Council for a Strategy for Hydrogen and Fuel Cells (2019) were used for hydrogen prices. For energy prices, the carbon price is assumed to be a maximum of ¥40,000/t CO_2 up to 2050. Furthermore, it is assumed that a portion of tax revenues will be used to subsidize electric vehicles, fuel cell vehicles and electric heat pump water heaters.

(3) Constraints on Energy Supply

It was assumed that about 30% of the hydrogen and synthetic fuels supply will be dependent on imports and 100% of ammonia will be imported.

Table 1 Major future activities and conditions.

	FY2018	FY2050
GDP growth rate	2020–2030 2031–2050	1.7% 0.5%
Population (000)	126,440	101,923
Number of households (000)	53,889	47,241
Crude steel production (million tons/year)	102.9	85.7
Cement production (million tons /year)	60.2	60.4
Ethylene production (million tons /year)	6.2	5.4
Paper/paperboard production (million tons /year)	26.0	23.4
Machinery production (2015 = 100)	100	141
Commercial floorspace (million m^2)	1,903	1,671
Passenger transportation (billion person-km)	1,459	1,179
Freight transportation (billion t-km)	411	419

Table 2 Energy-related CO_2 emission reduction measures.

Countermeasure Pillars	Context of Measures
1) Reduction of demand for energy services	Industry*: Extend product service life, resource-saving design, shared use, circular use, use of wood for structures
	Commercial/Residential: Increase building insulation, energy management
	Transportation*: Reduce transportation of persons and goods through digitalization, improve transportation efficiency
2) Improved energy efficiency	All Sectors: Improve efficiency of energy consuming equipment
3) Promotion of electrification	Industry: Use heat pumps to supply low and medium heat, increase use of electric furnaces
	Commercial/Residential: Increase use of heat pumps for heating and hot water supply
	Transportation: Electric and fuel cell vehicles
4) Decarbonization of energy	Generation: Renewable energy, CCUS
	Industry: Hydrogen direct reduced iron, CCUS
	All sectors: Increase use of hydrogen and synthetic fuels

* These are considered in the “technology + social transformation” scenario discussed later.

Table 3 Reduction measures for GHG emissions other than energy-related CO_2.

Countermeasure Pillars	Main Measures
Industrial Processes	Reduction of clinker ratio, CCUS
Agriculture related	Agricultural soil measures, Control measures for rice paddy and livestock origin CH_4, N_2O
Waste management	Promotion of 3R measures, Reduced use of petroleum derived products
Four Gases incl. alternative CFC	Development and deployment of low GWP gases, prevention of leakage, capture and treatment

The upper limit for the deployment of renewable energy was set by referring to the Ministry of the Environment’s Renewable Energy Potential System (REPOS) (2020). For example, the upper limits for solar photovoltaic, onshore wind power and offshore wind power were set at 350 GW, 118 GW and 178 GW, respectively.

(4) Scenarios

The Intergovernmental Panel on Climate Change (IPCC) is analyzing emission pathways that would limit the increase in average global temperature to 1.5°C (IPCC, 2018, 2022). We have analyzed emission pathways based on low energy demand scenarios assuming that decarbonization of the energy system will be induced by demand-side transformations of society, business and technology. Compared to other scenarios, there will be lower future dependence on negative emissions, and the total amount of renewable energy deployed will be smaller.

To examine the effects of social transformation in Japan, we analyzed future emissions and other factors for two scenarios to achieve net zero emissions: a “technology” scenario based on the deployment of decarbonization technologies including energy conservation, renewable energy and electrification and a “technology + social transformation” scenario that assumes digitalization and a move towards circular economy in addition to the deployment of decarbonization technologies.

The low energy demand (LED) scenario (Grubler et al., 2018) adopted by the IPCC (2018) was referenced for the “technology + social transformation” scenario. For the industrial sector, it is assumed that the volume of goods produced will be reduced by 15% in 2050 compared to the “technology” scenario due to more efficient use of materials including longer product service life, resource-saving design and sharing. For the transportation sectors, it is assumed that the volume of passenger and freight transportation will be reduced by 20% in 2050 compared to the “technology” scenario due to reduction in demand and increased efficiency from digitalization and dematerialization. No differences between the two scenarios were assumed for the commercial and residential sectors.

3. Simulation Results

3.1 Final Energy Consumption by Sector

Energy consumption in the final energy consumption sectors was estimated by using AIM/Enduse. The results are shown below.

(1) Industrial Sector

Figure 3 shows the final energy consumption for the industrial sector in 2018 and 2050. Compared to 2018, final energy consumption in 2050 is 22% lower for the “technology” scenario and 33% lower for the “technology + social transformation” scenario. The effect of social transformation, as evaluated by comparing the “technology” and “technology + social transformation” scenarios for 2050, is estimated to be a 15% reduction. Also, the effect of deploying countermeasure technology was calculated by comparing energy consumption for 2050 in both scenarios with a “fixed technology” scenario while holding activity constant; the reduction is estimated to be 21% for both scenarios. Fossil fuel consumption is about 90% lower in 2050 than in 2018. Although coal is still consumed in 2050, it is only consumed by the steel and cement industries and both industries have installed

CO_2 capture technologies for coal consumption. In contrast, the shares of electricity, hydrogen and synthetic fuels increase. For both scenarios from 2018 to 2050, the share of electricity increases from 20% to 34%, hydrogen from 0% to 23%, and synthetic fuels from 0% to 18% (percentages of consumption as energy excluding non-energy use).

(2) Commercial and Residential Sectors

Figure 4 shows the final energy consumption in 2018 and 2050 for the commercial and residential sectors. The commercial and residential sectors generally show similar trends. As there are no differences in the assumptions between the "technology" and "technology + social transformation" scenarios for the two sectors, only one energy consumption is shown for each sector in 2050.

Final energy consumption in 2050 is 51% lower for the commercial sector and 53% lower for the residential sector compared to 2018. Also, the effect of deploying countermeasure technology, as evaluated by comparing energy consumption of both scenarios with a scenario using "fixed technology" while holding activity constant, is estimated to be 55% for the commercial sector and 45% for the residential sector. By energy type, the share of fossil fuel decreases while the share of electricity increases. Between 2018 and 2050, electricity as a share of final energy consumption increases from 54% to 93% in the commercial sector and from 51% to 74% in the residential sector. Regarding energy consumption by application, large decreases in energy consumption are seen in both sectors for air conditioning/heating and hot water supply compared to 2018, with a 76% reduction for the commercial sector and a 61% reduction for the residential sector for air conditioning/heating and an 81% reduction for the commercial sector and a 73% reduction for the residential sector for hot water supply.

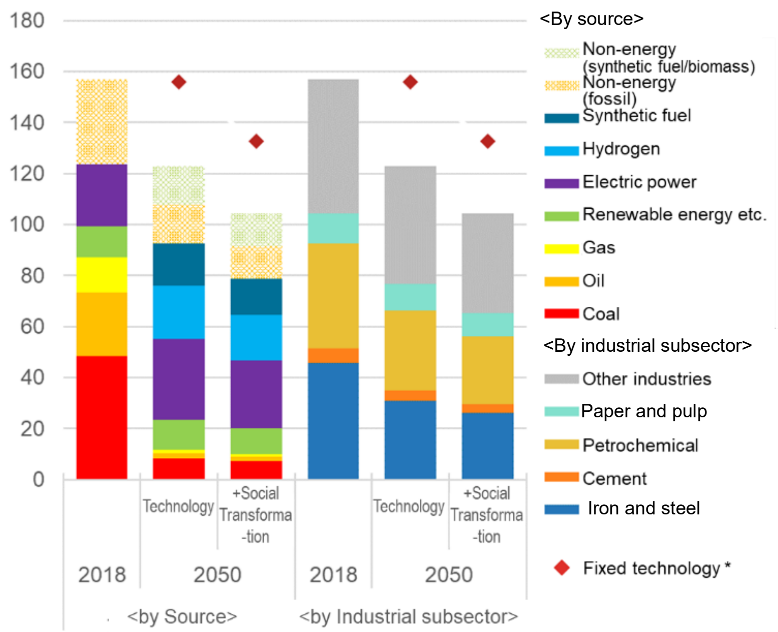

Fig. 3 Final energy consumption in the industrial sector (Mtoe).

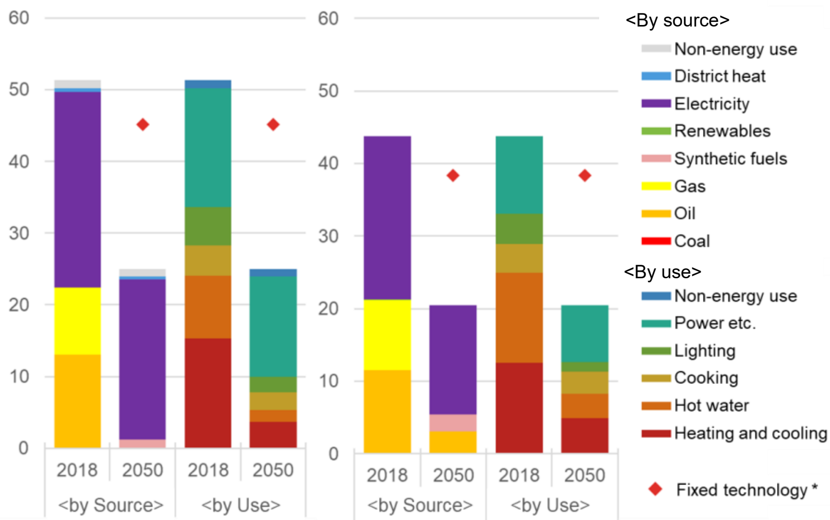

Fig. 4 Final energy consumption in the commercial and residential sectors (left: commercial, right: residential, Mtoe).

(3) Transportation Sector

Figure 5 shows the final energy consumption for the transportation sector for 2018 and 2050. Compared to 2018, final energy consumption in 2050 is 74% lower for the “technology” scenario and 79% lower for the “technology + social transformation” scenario. The effect of social transformation, as evaluated by comparing the “technology” and “technology + social transformation” scenarios, is estimated to be a 20% reduction. Also, the effect of deploying countermeasure technology, as evaluated by comparing both scenarios to a scenario using “fixed technology” while holding activity constant, is estimated to be a 72% reduction for both scenarios. Regarding energy consumption by application, passenger vehicles and freight vehicles currently account for a high proportion of energy consumption in the transportation sector and significant reductions in energy consumption by both vehicle types (passenger vehicles: 88%–91% reduction, freight vehicles: 66%–72% reduction) contribute greatly to the overall reduction in energy consumption.

Regarding the energy mix, the proportion of fossil fuels decreases and the proportions of electricity, hydrogen and synthetic fuels increase. In 2018, electricity was used only for railroads and did not exceed 2% of the energy used for transportation while hydrogen and synthetic fuels were not consumed. In 2050, the proportion of electricity increases to 41% while hydrogen increases to 21%–22% and synthetic fuel to 24%–26%. By 2050, almost 100% of passenger vehicles will be electric vehicles. In contrast, as the use of batteries for storing energy for freight vehicles will result in the extremely high weight of batteries, a portion of freight vehicle will be non-electric vehicles including hydrogen fuel cell vehicles (accounting for 35% of energy consumption) and internal combustion locomotives powered by synthetic fuels (accounting for 32% of energy consumption).

(4) Final Energy Consumption Sector

Figure 6 shows the final energy consumption for 2018 and 2050 for the final energy consumption sector, which is the sum of the industrial, commercial, residential and transportation sectors. The total final energy consumption for 2050 compared to 2018 is reduced by 42% for the “technology” scenario and by 49% for the “technology + social transformation” scenario. The effect of social transformation, as evaluated by comparing energy consumption in 2050 for the two scenarios, is estimated to be a 12% reduction. Also, the effect of deploying countermeasure technologies, as evaluated by comparing both scenarios with a “fixed technology” scenario while holding activity constant, is estimated to be a 39% reduction for both scenarios. Regarding the energy mix, the proportion of fossil fuels decreases while the proportion of electricity, hydrogen and hydrogen-based fuels increases. The proportion of electricity increases from 26% in 2018 to 49%–51% in 2050 while the proportion of hydrogen and hydrogen-based fuels increases from no consumption in 2018 to 31%–33% in 2050.

(5) Demand for Hydrogen and Hydrogen-based Fuels

Figure 7 shows the demand for hydrogen and hydrogen-based fuels in 2050. The demand for hydrogen is 52–61 million tons oil equivalent (Mtoe). Hydrogen is necessary for producing synthetic fuels, and demand for synthetic fuel production accounts for more than 50% of total hydrogen demand. Demand for synthetic fuel is 34–40 Mtoe, with industrial use (including non-energy use) accounting for about 80% of demand. Demand for ammonia in 2050 will be 17 Mtoe, mostly for electricity generation.

In Japan, synthetic fuels will be produced using CO_2 captured from electricity generation or the industrial sector. Excluding CO_2 captured from biomass power generation used for synthetic fuel production, consumption of synthetic fuels produced from CO_2 from

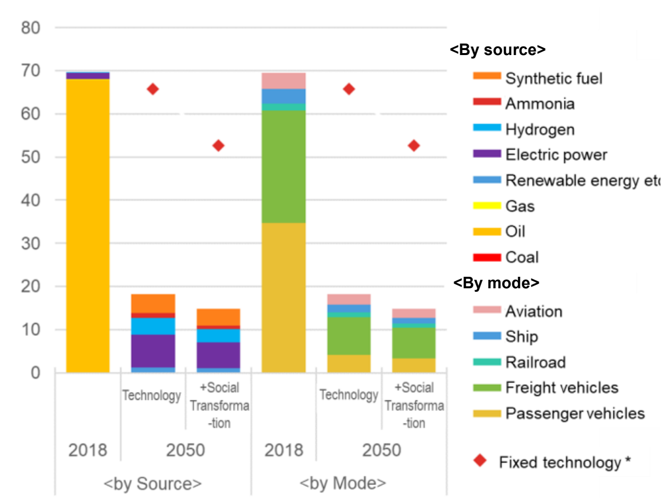

Fig. 5 Final energy consumption in the transportation sector (Mtoe).

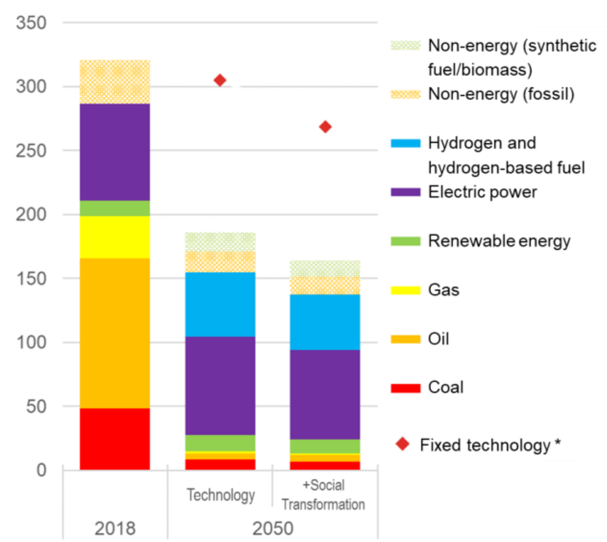

Fig. 6 Final energy consumption (Mtoe).

fossil fuels and limestone is included in CO_2 emissions.

(6) Demand for Electricity

Figure 8 shows the demand for electricity for 2018 and 2050. Electricity demand in 2050 will increase by 30%–46% compared to 2018. While the demand for final consumption sectors (industrial + commercial + residential + transportation) will decrease, the demand for production of hydrogen and hydrogen-based fuels (primarily for electrolytic hydrogen production) will increase.

3.2 Electricity Generation

The electricity demand estimated by AIM/Enduse was downscaled to 8,760 hours (24 hours x 365 days) by the EPCOs' jurisdiction areas (10 regions). In the model, electricity demands for hydrogen production have been allocated as surplus electricity while keeping the capacity factor of hydrogen production facilities more than 60%. The electricity demand for hydrogen and synthetic fuel production was assumed not to be constrained by region or time.

Figure 9 shows electricity generation in 2018 and 2050, while the mix of renewable energy power generation is shown in Fig. 10. The share of decarbonized power sources in electricity generation increases from 25% in 2018 to 100% in 2050. The proportion of renewable power generation increases from 17% in 2018 to 73%–76% in 2050; solar photovoltaic generates 403–405 TWh in 2050, while onshore wind generates 133–226 TWh, and offshore wind generates 205–276 TWh.

3.3 Domestic Primary Energy Supply

Currently, fossil fuels account for more than 80% of Japan's primary energy supply. Renewable energy sources will account for about 70% of primary energy in 2050. This represents an improvement in energy self-sufficiency from 15% in 2018 to more than 70% in 2050.

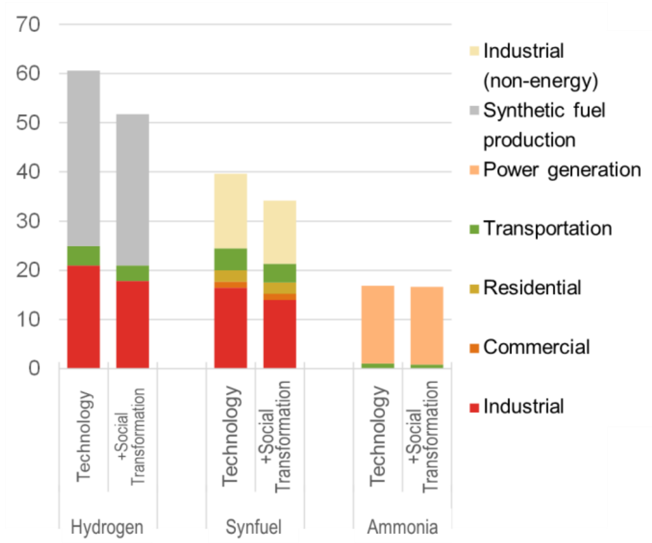

Fig. 7 Demand for hydrogen and hydrogen-based fuels (2050, Mtoe).

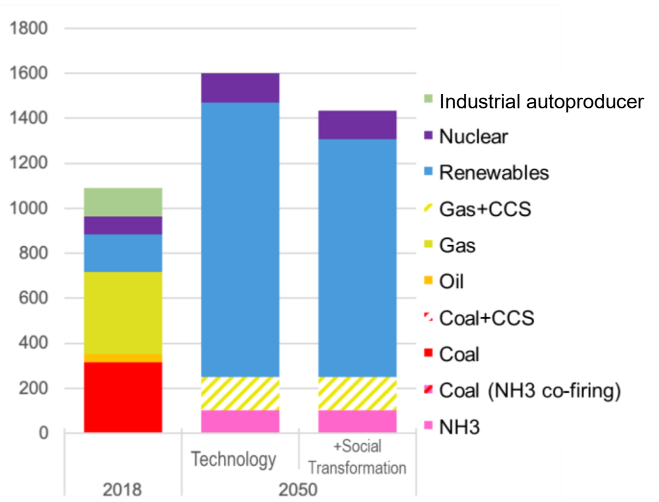

Fig. 9 Power generation mix (TWh).

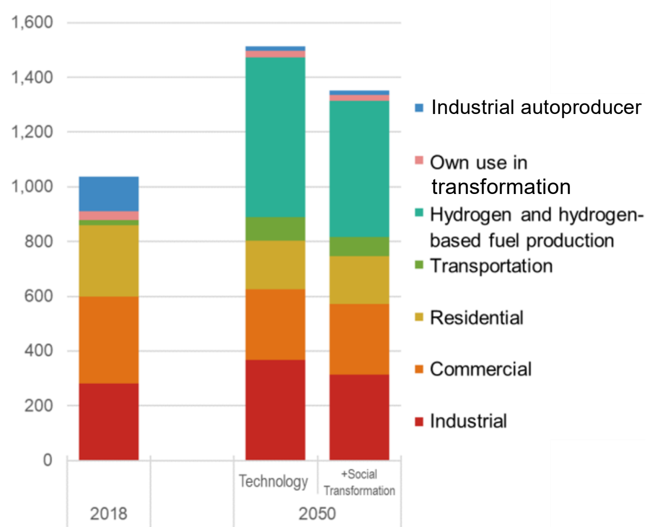

Fig. 8 Electric power demand (TWh).

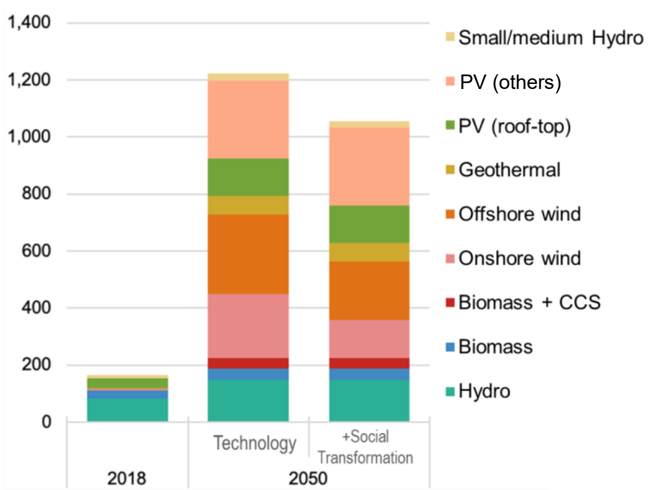

Fig. 10 Renewable energy power generation mix (TWh).

3.4 CO_2 Capture and Use

CO_2 capture in 2050 will be 147–157 million tons of CO_2 ($MtCO_2$). CO_2 will be captured from the steel, cement and petrochemical industries in the industrial sector and natural gas-fired and biomass-fired thermal power plants in the power generation sector. Of the captured CO_2, 49–57 $MtCO_2$ will be used to produce synthetic fuels, and the remaining 97–99 $MtCO_2$ will be stored underground.

3.5 GHG Emissions

Figure 11 shows GHG emissions for 2018 and 2050. Emissions from the consumption of synthetic fuels account for a considerable proportion of energy-related CO_2 emissions in 2050. Some GHG emissions will be unavoidable in 2050 even if decarbonization measures are promoted. Our analysis estimates total GHG emissions of 102–114 $MtCO_2$, broken down as follows: 55–65 $MtCO_2$ from energy-related CO_2; 19–22 $MtCO_2$ from non-energy-related CO_2; and 27–30 $MtCO_2eq$ from methane, N_2O and the four gases including CFC alternatives. Forest sequestration, bioenergy with carbon dioxide capture and storage (BECCS), and other negative emission technologies will be required to offset these emissions.

3.6 Additional Investment Amount

Figure 12 shows the annual average additional investment from 2041 to 2050. The amount of investment required for insulation of houses and other buildings and renewable energy accounts for a considerable proportion of the additional investment.

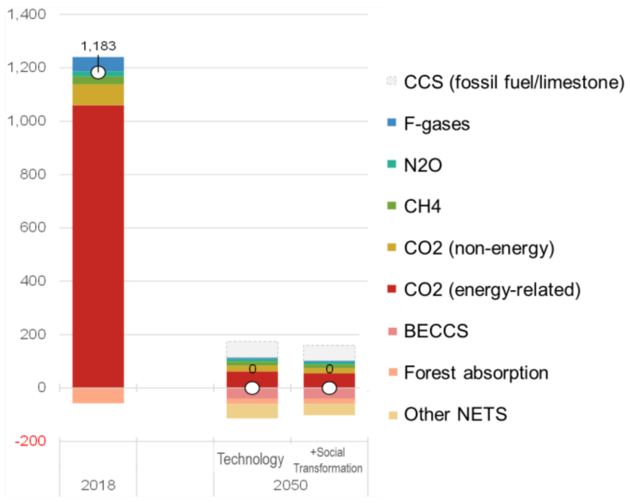

Fig. 11 GHG emissions (MtCO2eq).

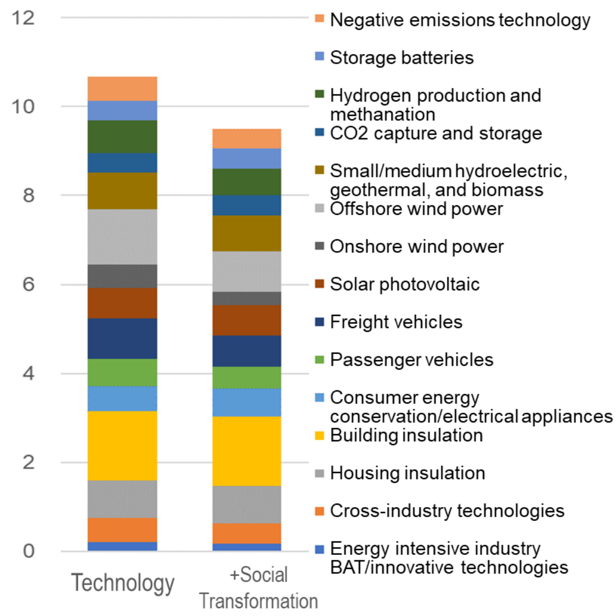

Fig. 12 Additional investments (annual average: 2041–2050, trillion yen).

4. Towards Realization of a Decarbonized Society in Japan

4.1 Conversion of the Energy System

As energy-related CO_2 emissions accounted for 84% of Japan's GHG emissions in FY2020 (Ministry of the Environment, 2022), decarbonization of the energy system is the most critical issue for achieving net zero GHG emissions. Based on our analysis, the key points for the energy system in 2050 are as follows:

(1) Reduction of energy demand by 40% to 50% through social transformation and deployment of technologies for improving energy efficiency.

(2) Regarding reduced final energy demand, promotion of electrification so that the proportion of electricity in final consumption is 50% (26% in 2018).

(3) As the electrification of all energy applications will be difficult, use of hydrogen and hydrogen-based fuels for industrial applications for high-temperature heat, large-scale transport, and other fields where electrification is difficult.

(4) However, as electricity will be required to produce hydrogen and hydrogen-based fuels, combined with the electrification of the final consumption sector, the amount of electricity generated is estimated to increase by more than 30% from current levels. Power generation will be provided by 100% decarbonized power sources. This will require the supply of electricity from renewable energy sources to increase to more than five times the current level of 200 billion kWh.

(5) In addition, 150 million tons of CO_2 will be captured from the remaining consumption of fossil fuels for electricity generation and industrial applications. About one-third of the recovered CO_2 will be used to produce synthetic fuels while the remaining 100 million tons of CO_2 will need to be stored underground.

(6) Annual investment of about 10 trillion yen will be required for the decarbonization of the energy system.

Currently, fossil fuels account for 70% of final energy consumption, and fossil fuel-fired thermal power generation accounts for 70% of electricity generation. The fossil-fuel-based energy system will need to be transformed into the renewable-energy-based energy system described above.

4.2 Deployment of Negative Emission Measures

It is extremely difficult to completely control GHG emissions and reduce emissions to net zero without offsetting emissions with sequestration. Our estimates show that in 2050 the use of synthetic fuels, GHG emissions including CO_2 emissions from industrial processes and waste incineration, and emissions of CH_4 and N_2O from the agriculture and livestock industries will result in GHG emissions of about 100 $MtCO_2$, which is equivalent to about 10% of GHG emissions in 2018. The only negative emissions measure aimed at capturing CO_2 from the atmosphere currently being implemented is CO_2 sequestration by forests; in 2020, 57 $MtCO_2$ were estimated to be sequestered by forests in Japan (NIES, 2022). However, as Japanese forest plantations age, the amount sequestered by forests will tend to decrease (MAFF, 2021) and significant increases in sequestration cannot be expected. Thus, other negative emission measures including BECCS, direct air capture (DAC), biochar, and blue carbon management will be required (IPCC, 2022). However, these measures are in the R&D stage and have not reached the stage of widespread deployment. To increase the possibility of Japan achieving net zero emissions, promotion of R&D and acceleration of deployment for these technologies will be necessary.

4.3 Social Transformation Toward a Decarbonized Society

In this analysis, we attempted to calculate the effect of social transformation on the reduction of GHG emissions by using two scenarios. The effects of dematerialization on goods production (15% reduction in goods production) and the effects of digitalization and dematerialization on demand for transportation (20% reduction in demand for transportation) were considered in the "technology + social transformation" scenario. The "technology + social transformation" scenario led to a 12% reduction in final energy consumption compared to the "technology" scenario.

Achieving social transformation increases the likelihood of achieving a decarbonized society. Achieving net zero emissions will also depend on the deployment of decarbonization technologies that are currently not widely used. However, there is a high degree of uncertainty regarding various social, economic and technological aspects associated with the deployment of these technologies. Thus, reduction of energy demand through social transformation will reduce the dependence on highly uncertain technologies and increase the possibility of achieving a decarbonized society. In this analysis, the scenario including social transformation reduces the dependence on currently undeployed decarbonization technologies, including the amount of negative emission technology required (55→43 $MtCO_2$); reduces imports of hydrogen and hydrogen-based fuels (47→42 Mtoe); and reduces wind power deployment (276→205 TWh).

5. Implications for Achieving a Decarbonized Asia

5.1 Renewable Energy Power Generation

Our analysis of Japan suggests that a significant increase in renewable energy generation will be necessary to achieve carbon neutrality. The transition from thermal power generation to solar and wind power generation, which are highly variable, will be a challenge. Currently, the share of thermal power generation in the power generation mix in Asian countries is about 70% in all major countries and regions (Japan 73%, China 67%, India 76%, ASEAN 76% in 2020, (IEA, 2022). On the other hand, there are differences in the amount of electricity generated per capita. Japan's per capita generated electricity has remained at 8–9 MWh/year/person for the past 20 years. China's was around 1 MWh/year/person in 2000 and reached 5.5 MWh/year/person in 2020. India and ASEAN are 1.1 and 1.7 MWh/year/person, respectively, in 2020 (IEA, 2022). A large number of new power plants are expected to be built in India and ASEAN. Considering that thermal power generation has a lifetime of about 40 years, the newly built plants will remain in 2050. Therefore, those plants that are not ready for CCUS or conversion to hydrogen-based fuels will become stranded assets with respect to CN realization. Future new construction should be shifted mainly to renewable energy generation. To this end, it will be essential to strengthen the power grid in parallel.

5.2 Hydrogen-based fuel

In areas where electrification is difficult, such as high-temperature thermal applications in the industrial sector and freight vehicles, ships and aviation in the transportation sector, Japan's analysis suggests that the use of hydrogen-based fuels is inevitable for decarbonization. This is true for all countries, where these applications exist, and the supply of hydrogen-based fuels is a common challenge. The production of carbon-free hydrogen fuels will either be based on fossil fuels, with sequestration and storage of carbon emissions, or by electrolysis using renewable energy generation. In order for synthetic fuels to be decarbonized, their carbon source must be of biomass origin or atmospheric CO_2. In the production of new fuels, it will be necessary to use production that takes advantage of the characteristics of each country and, in countries with large production potential, to create production plans not only for their own use but also for export in order to realize a decarbonized society for the entire world.

5.3 Response to Negative Emissions

In Asia, especially in Southeast Asia, there are countries with abundant forest resources. In such countries, expansion of forest sinks is incorporated into their strategies to achieve carbon neutrality. For example, Indonesia and Thailand, in their long-term strategies, expect to absorb 300MtCO_2 or 120MtCO_2 in 2050, respectively (Indonesia, 2021; Thailand, 2022). On the other hand, some countries are not expected to absorb much from forests due to climate and land area. Therefore, countries with abundant forest resources are expected to take measures to use these resources not only to reduce the burden of their own energy-related CO_2 reduction measures, but also as offsets for resource-poor countries and regions.

In addition to forests, negative emission measures include soil carbon sequestration, blue carbon, biomass CCS, and other measures that incorporate natural uses, as well as DAC, which captures CO_2 directly from the atmosphere through chemical reactions. These measures are also expected to take advantage of the characteristics of the natural environment, not only within each country, but also for decarbonization of the world as a whole.

5.4 Necessity of Social Transformation

Our analysis of Japan suggests that achieving social transformation will increase the certainty of achieving a decarbonized society. There are countries in Asia that are currently still in the developing stage, where material demand will increase significantly in the future due to improved capital development and the diffusion of durable consumer goods. For example, per capita steel consumption (production + exports - imports) in Japan and China exceeded 500 kg in 2018 (Japan 560 kg, China 609 kg), while in Thailand and Vietnam, consumption was about half that amount (Thailand 322 kg, Vietnam 262 kg), and in India and Indonesia it was about one-eighth (India 77 kg, Indonesia 68 kg) (World Steel Federation, 2019). In 2020, per capita car ownership was 0.62 in Japan, 0.20 in China, 0.28 in Thailand, 0.11 in Indonesia and 0.05 in India (estimated from JAMA, 2022 and UN, 2022), with India's less than one tenth of Japan's. For the least developed countries, building social capital for efficient material use and creating cities that do not become car-dependent will, in the long run, lead to a shortcut toward a decarbonized society.

Summary

The realization of a decarbonized society will require efforts to achieve zero emissions from all emission sources as well as a drastic transformation of the energy consumption mix. Our analysis shows that promoting social transformation will substantially increase the possibility of achieving a decarbonized society.

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