Carbon Neutral Energy System Analysis in Japan using TIMES-JAPAN Model

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Overview

With the entry into force of the Paris Agreement, the decarbonization of the global energy sector has become a long-term imperative. In addition, the 1.5°C Special Report of the Intergovernmental Panel on Climate Change (IPCC) and other reports have prompted Japan to set a goal of zero net greenhouse gas (GHGs) emissions by 2050, and the movement toward zero net GHGs by the middle of this century is accelerating worldwide.

Therefore, there is a greater need than ever before to study the overall supply and demand of energy toward 2050, taking into account measures in the energy sector (demand, renewable energy generation, and the introduction of zero-emission energy carriers such as hydrogen) as well as the operation of electricity supply and demand based on a new power supply structure. Specifically, it is adequate to examine the entire energy system, including the electric power system, the building sector such as residential and commercial, the transportation sector, and the industrial sector, all of which are expected to undergo significant changes, based on the assumption of the macro conditions of future society, lifestyles, applicable technologies, and their diffusion. Therefore, we present the results of our calculations of the energy supply and demand system and CO2 emissions and discuss the energy choices and their impact on Japan's long-term goal for 2050. In order to examine Japan's energy supply and demand in 2050, we conducted a soft-link analysis between the TIMES-JAPAN optimization model, which is a bottom-up analysis of Japan's entire energy system, and the detailed power supply planning model, and the detailed building sector model, keeping the consistency among these models.

Methods

The model structure of TIMES-JAPAN is an optimization type model that covers from 1990 to 2050 and treats the entire Japan as one region. The objective function is the total cost after discounting for future periods. For electricity, the year is divided into six time-slices, day and night, for the intermediate, winter, and summer periods, and the maximum annual load is taken into account to represent the load curve simply. Bioenergy with CO2 Capture and Storage (BECCS) and Direct Air Capture with CO2 Storage (DACCS) are considered as negative emission technologies. Moreover, the sensitivity analysis for carbon-neutral LNG, where the carbon content is offset during production by means such as Direct Air Capture (DAC) and the net CO2 is considered to be zero after combustion. We set the upper limit of photovoltaic, wind, and nuclear power generation capacity concerning power generation. The nuclear power scenario assumes 60-year extended operation. The final energy demand is based on the SSP2 scenario, the most moderate Shared Socioeconomic Pathways (SSP) adopted in the Japan Model Intercomparison Project (JMIP). Fossil fuel import prices are based on the International Energy Agency's World Energy Outlook scenario. We assume that carbon-neutral fuels can be imported to Japan at the same price level as liquid hydrogen.

Results

Two types of long-term CO2 reduction paths were assumed in the analysis. In the former reduction target, the 2030 reduction follows the GHG reduction target of 26% compared to 2013, and the CO2 reduction from the energy system in 2050 is an 80% reduction compared to the base year. The new policy reduction target is 46% in 2030 and net-zero emissions in 2050, but 40 million tons of CO2 emissions can be offset by land-use sequestration, and the same amount of energy-related CO2 emissions are allowed in 2050. Negative emission technologies can be used only under the new reduction targets. According to the reduction target strength, we set two upper limits of annual CO2 storage volumes. The other sensitivity is the availability of carbon-neutral fuels.

The portfolio of primary energy supply, electricity generation, industrial, consumer, and transportation energy demand, and CO2 emissions in 2050 are calculated. The share of fossil fuels decreases significantly for primary energy supply, and the share of renewable energy increases significantly. Imported carbon-neutral fuels, such as imported hydrogen and synthetic fuels, are also introduced. As for the amount of electricity generated, the share of solar and wind power will increase significantly in 2050 compared to the current situation, although the increase in their share will be lower than the increase in installed capacity because their installed utilization ratio is lower than that of thermal and nuclear power. As a result, in the power supply mix in 2050, zero-emission in the power generation sector is achieved when thermal power with CCS is taken into account. As for the industrial energy demand, the share of fossil fuels does not decrease significantly, reflecting the fact that the simulation assumes that fossil resources are used as raw materials, such as oil as a chemical raw material and coal as a reductant material in steel and cement and that there is a certain amount of material production. The results show that the share of fossil fuels does not decrease significantly. However, there are some behaviors such as the substitution of blast furnaces for electric furnaces and hydrogen reduction iron and steel production, and CCS in cement. In the 2050 net-zero emissions case, the CO2 constraint is relaxed in the carbon-neutral fuel introduction case, and the fossil fuel demand slightly increases. Consumer energy demand, both business and residential, is significantly electrified in 2050, leading to a significant decrease in the final demand share of fossil fuels. As for transportation energy demand, GHG emissions from international transportation demand are not included in the CO2 reduction target according to the GHGs emission calculation method of the United Nations Framework Convention on Climate Change. However, to reflect the need to reduce CO2 emissions from international transportation, the analysis assumes that a certain percentage of hydrogen, natural gas, and synthetic fuels will be introduced into international transportation. In the transportation sector, the share of oil has changed significantly in response to CO2 reduction, and the shares of electricity and hydrogen have also increased significantly.

The net-zero CO2 emission condition for 2050 allows for emissions offset by sinks, but even with such a condition, negative emissions such as BECCS and DACCS were observed based on the assumption that large amounts of CO2 can be stored. The importance of the negative emissions is evident. By sector, the share of industrial sector emissions is high, suggesting that CO2 reduction measures in the industrial sector are challenging under the current conditions of the existence of fossil resources as carbon-containing raw materials, the assumption that material production will not change significantly, and the lack of drastic alternatives for high-temperature heat demand.

It is suggested that carbon-neutral fuels will play essential roles in reducing CO2 emissions from various sectors. Sensitivity analysis of 2050 carbon-neutral cases was conducted assuming carbon offset LNG presence/absence and different wind power potential. The future share of carbon-neutral fuel imports to Japan would reach around 10% of the primary energy supply. However, the demand portfolio of hydrogen, ammonia, and carbon-offsetted LNG is quite different. For example, mobility would be the primary application for hydrogen and ammonia for industry and navigation use. Carbon offset LNG could be used in industry and for feedstock of hydrogen.

Conclusions

Conscious of the net-zero emissions target of the Paris Agreement for the middle of this century and beyond, an analysis of Japanese energy system was conducted assuming that Japan will achieve significant long-term CO2 reductions. In addition to electricity and hydrogen, introducing new zero-emission carriers called carbon-neutral fuels, including offsets from overseas, is increasing, a common trend in all sectors, but CO2 reduction in the industrial sector is relatively difficult. The importance of importing CO2-free energy carriers, such as hydrogen and other gaseous and liquid fuels, is also shown since domestic renewable energy resources are limited. Furthermore, as a demand-side scenario, the demand for transportation services due to lifestyle changes such as a significant increase in telecommuting and social changes such as industrial structure including information technology is assumed. In addition, it is necessary to study detailed social scenarios for these demand-side factors. In addition to the perspectives of securing investment funds, dissemination of technologies including market design, and institutional aspects for social acceptance, the feasibility of net-zero GHG emissions should be examined. The feasibility of net-zero GHG emissions should be studied comprehensively from the perspective of securing investment funds, the institutional perspective for technology diffusion and social acceptance, including market design, and natural scientific knowledge other than energy. It is also necessary to continue adjusting the interface between the power system models and detailed building energy demand.