Systems Analysis Group

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Research Activities in Systems Analysis Group

The Systems Analysis Group aims to provide valuable information about response measures to global warming and energy issues through systematic approaches and analyses at both national and international levels.

In February 2025, the 7th Strategic Energy Plan[1)], the Plan for Global Warming Countermeasures[2)], and the Green Transformation (GX) 2040 Vision[3)] were formulated and approved by the Cabinet. RITE presented quantitative scenario analyses using energy systems models and provided supporting information to formulate these plans during each of the discussions. This report explains the scenario analyses presented in the discussion for formulating the Strategic Energy Plan.

1. Background of scenario analyses regarding Strategic Energy Plans

The “Paris Agreement[4)],” which was adopted at the 21st Conference of the Parties (COP21) of the United Nations Framework Convention on Climate Change (UNFCCC) at the end of 2015, came into effect in November 2016. Under the Paris Agreement, it was agreed to keep the global mean temperature rise well below 2°C above pre industrial levels and to pursue efforts to limit it to below 1.5°C. Subsequently, in November 2021, the 26th Conference of the Parties (COP26) was held in Glasgow, UK, where they agreed to pursue efforts to limit global temperature rise to 1.5°C. On the other hand, progress has been limited in deepening the Nationally Determined Contributions (NDCs), emission reduction targets pledged voluntarily by each country stipulated in the Paris Agreement. Even if all current NDCs were achieved, there would still be significant gaps not only with the 1.5°C but also with the 2°C emissions pathways[5)]. Moreover, based on the recent emission trends, it seems becoming difficult for many countries to meet their NDCs targets. While the international community mostly agrees on the need to strengthen climate change measures, there are differing views on specific approaches. In order to achieve global carbon neutrality (CN), it is essential to address competitive imbalances due to the differences in national ambition levels and policy strength, preventing carbon leakage.

In June 2019, the Government of Japan formulated the "Long-term Strategy under the Paris Agreement[6)]," which stated Japan’s commitment to reaching net zero emissions as early as possible in the second half of the

21st century. Then, in October 2020, the then Prime Minister Suga declared the goal of achieving CN and a decarbonized society by 2050 in his policy speech. Furthermore, the Plan for Global Warming Countermeasures[7] was revised in 2021, and the greenhouse gas (GHG) emissions reduction target as the 2030 NDC was raised from a 26% reduction compared to FY2013 levels to a 46% reduction, with further striving for a 50% reduction.

On the other hand, in 2022, issues surrounding energy security and stable supply became more apparent. The surge in fossil fuel prices due to the Russia-Ukraine situation and the electricity supply-demand crisis in March 2022 led to a renewed awareness of the importance of energy security. In response, under then Prime Minister Kishida, the "Basic Policy for the Realization of Green Transformation (GX)[8]" was approved by the Cabinet in February 2023.

Against this background, the 7th Strategic Energy Plan[1], the Plan for Global Warming Countermeasures[2], and the GX 2040 Vision[3] were formulated in December 2024, and approved by the Cabinet in February 2025. The GHG emissions reduction targets of 60% by 2035 and 73% by 2040 (both compared to FY2013 levels) were decided in the plans and submitted to the UNFCCC as Japan's updated NDC in February 2025. These plans respond to the increasing need for enhanced climate change measures both domestically and internationally, while also addressing emerging risks related to energy security and stable supply, climate actions, and trade relationship. They also intend to implement industrial policies and energy and climate measures in a comprehensive manner.

2. Overview of countermeasures toward Carbon Neutrality

For the analyses of the 7th Strategic Energy Plan and related policies, it was requested to be based, in principle, on the assumption of achieving CN by 2050, in line with the Japanese government's policies to date. Therefore, before explaining the model analyses, this section aims to provide an overview of the measures for achieving CN.

Figure 1 illustrates the realization of CN from the perspective of primary energy supply. Decarbonization of energy is essential for achieving CN, however, each energy source that can contribute to decarbonization has technical, social, and economic constraints. Therefore, from the perspective of minimizing total costs, energy saving remains crucial for achieving CN. Social innovations including sharing and circular economy associated with digital transformation (DX) will be increasingly important as well as energy savings of each technology.

On top of that, it is necessary, in principle, to build a supply structure consisting of renewable energy (RE), nuclear power, and fossil fuels with carbon capture and storage (CCS) or carbon dioxide removal (CDR) technologies, and proceeding electrification will be important for achieving CN on the final energy side. While electricity can be directly decarbonized through nuclear power and renewable energy, non-electric energy needs to be converted to other forms such as hydrogen-based energy, which tends to be more costly. Thus, promoting electrification, by means of heat pump water heaters, electric vehicles, and so on, is important. On the other hand, there are many high-temperature demand applications unsuitable for electrification, and diverse individual consumers make uniform electrification physically and economically difficult. Therefore, it is important to appropriately combine various energy types.

Moreover, variable renewable energy (VRE) sources, such as solar and wind power, often result in surplus energy at certain times when introduced on a large scale, therefore, converting them into hydrogen energy, in addition to storage in batteries, can serve as a key countermeasure. However, solar and wind power generated in Japan generally have huge constraints in terms of cost and volume compared to overseas, so from an economic efficiency perspective, it may be necessary to consider importing renewable energies or fossil fuels with CCS from abroad and converting them into hydrogen. Also, for further convenience, it could be highly important to combine hydrogen with nitrogen or captured CO_2 to produce ammonia, synthetic methane (e-methane), or synthetic fuels (e-fuels). Although the production of e-methane and e-fuels requires an additional process of synthesizing hydrogen with CO_2, they can be transported more cheaply than directly transporting hydrogen, which needs to be converted to liquid or other forms. Furthermore, it is advantageous that existing gas and oil infrastructure, as well as current gas appliances and internal combustion engine vehicles, can be utilized while possibly realizing CN. In any case, hydrogen and hydrogen-based energy sources, similar to electricity as secondary energy, can be produced from a variety of primary energy sources, have a wide range of applications, and contribute to achieving net-zero emissions. According to the economic calculations using the models described later, the supply of hydrogen and hydrogen-based energy is expected to be predominantly imported from overseas.

In the model analyses, optimal cost-minimizing energy systems are derived, including the transition process toward CN, under various assumptions about the costs and potentials of various energy sources, considering both domestic and import circumstances.

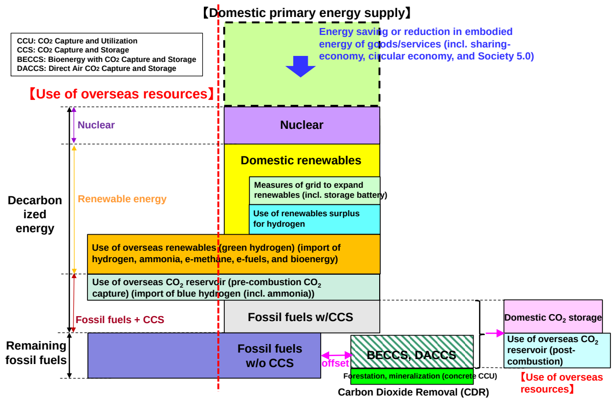

Figure 1 Image of primary energy for net-zero emissions

3. Scenario assumptions and analysis method

3.1. Scenario assumptions

Before explaining the scenario analysis methodology and the model outline, this section describes the scenarios presented to the government advisory council. Table 1 shows the assumed scenarios (in addition to those listed, a "Zero Nuclear Scenario" was also presented to the council, but it is omitted here due to space limitations). Figure 2 illustrates the map of these scenarios. It should be noted that as the Strategic Energy Plans present goals for the desired future, the "Low Growth Scenario," which RITE presented to the council as a scenario reflecting potential risks, is not included in the 7th Strategic Energy Plan.

In principle, the analyses assume existing government targets, the 1.5°C goal, CN by 2050, and a 46% emissions reduction by 2030. For 2040, a 73% reduction target (based on a linear reduction trajectory) presented by the government was assumed. The "High Growth Scenario" assumes that technological advancements progress rapidly and broadly in an innovative manner, with minimal barriers to technology diffusion, while the "Low Growth Scenario" assumes that technological progress remains gradual. As a case to avoid the associated economic risks, the "Risk Strategy Scenario" slightly relaxes emission constraints and applies carbon pricing in the analysis. In this scenario, the average values of carbon prices projected in the Net Zero 2050, the 2050 CN scenario, developed in the NGFS's three models are adopted.

3.2. Analysis method and overview of DNE21+

This section outlines the method and the models used for the analyses. For more detailed information on the models and the future technological assumptions in each scenario, please refer to Reference 9) and 10), and others. Figure 3 illustrates the procedure of the scenario analyses.

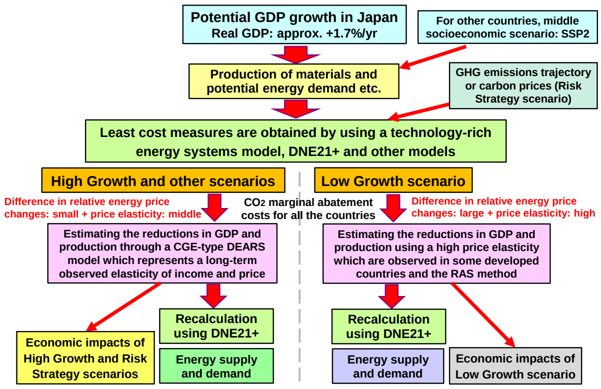

Figure 3 Estimation procedure for economic impacts and energy systems

Table 1 Assumed scenarios

Emissions scenarios	Scenario name	Scenario descriptions
Emissions reduction scenarios: [World] Below 1.5 °C (2030: NDCs) [Japan] 2030: -46% 2040: -73% 2050: -100% [Other major developed countries] 2050: -100%	**High Growth**	Broad technologies contributing to deep emissions reduction and net-zero emissions are rapidly improved. Social barriers of nuclear power, renewables, and CCS are also small. In this case, the relative prices of energy will keep also in the future.
	Renewables	High social acceptance of solar PV and onshore wind power, and rapid cost reductions in solar PV and wind power including offshore wind power
	Hydrogen	Rapid cost reductions in hydrogen including ammonia, e-methane and e-fuels
	CCS	Lower social barriers of CO_2 geological storage
	[Extreme risk] Low Growth	Incremental technology improvements. In this case, the relative prices of energy in Japan will increase due to limited potentials of net-zero emission technologies.
Carbon price scenario: The price targets consistent with 1.5 °C (based on the NGFS NZE2050 scenarios: 257 \$/tCO_2 in 2040, 500 \$/tCO_2 in 2050)	**Risk Strategy**	Technology improvements are conservative, and the energy and climate policies will have a carbon price target not to realize high relative prices of energy compared to those of overseas. The resulting GHG emissions will be higher than those in other scenarios which achieve net-zero emissions by 2050.

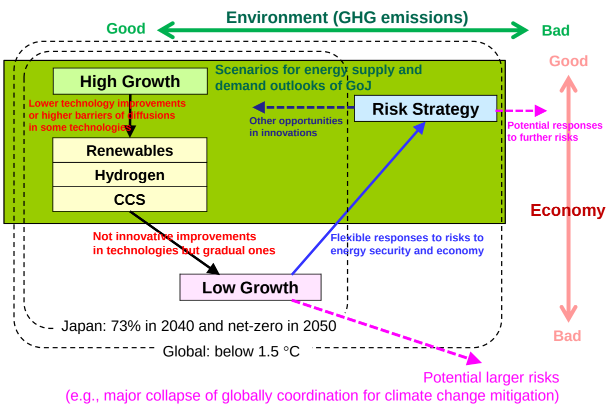

Figure 2 Map of the assumed scenarios

The analyses of the energy system were conducted using the global energy and climate change mitigation model, DNE21+. The DNE21+ divides the world into 54 regions and makes evaluation dynamically from the year 2000 to 2100. It is a bottom-up, technology-based model that includes not only the energy supply side but also a wide range of technologies on the demand side covering energy-intensive industries, residentials, transportation, and so on, which enables to present concrete policy measures.

DNE21+ is a partial equilibrium model that evaluates only the energy system and cannot assess the overall impacts on the macroeconomy. Currently, due to the differences in relative energy costs across countries, there is a trend that some industries, energy-intensive sectors in particular, relocate from developed to developing countries. However, since the DNE21+ exogenously assumes production volume scenarios for industries such as iron and steel and chemicals, it cannot evaluate the relocation of production volumes endogenously. Therefore, as shown in Figure 3, DEARS, a general equilibrium global energy-economic model, was also employed for the scenario analyses. The DEARS model is based on the international input-output tables of Global Trade Analysis Project (GTAP). Recently, an increasing price elasticity for electricity and energy is observed in some developed countries, especially in EU, and companies may be responding more swiftly to relative energy price differences in a globalized world. However, since the GTAP database has a large time lag in updates, it may not be able to reflect recent conditions accurately. Thus, in the "Low Growth Scenario," a high price elasticity for energy of −1.0 was adopted for the analysis. Based on the results of these estimates, the projected production volumes for energy-intensive industries and the transport machinery sector in the DNE21+ model were revised and calculated, and energy scenarios were presented.

4. Analysis results

This section presents the results of the scenario analyses.

4.1. Costs and economic impacts

Table 2 shows the marginal abatement costs of CO_2.

Even in the "High Growth Scenario," it is analyzed that achieving a 73% reduction by 2040 and CN by 2050 will require quite high costs. It is also considered that further innovations beyond what was assumed in this analysis will be needed to achieve these goals.

Under the "Low Growth Scenario," the marginal abatement cost of CO_2 is estimated to increase even more. Additionally, the relative costs compared to other countries will become larger, resulting in wider gaps of relative energy costs. Although this analysis assumes global emissions reduction pathways for the below 1.5°C target, in reality, global efforts may be uneven, with some countries implementing only baseline-level measures. In such cases, the gaps between Japan's electricity costs and those in other countries could widen even further in the "Low Growth Scenario." Therefore, it is important to consider a certain level of flexibility in emissions reduction strategies.

The "Risk Strategy Scenario" is designed to address such situations. Under this scenario, carbon prices equivalent to achieving CN by 2050 (below 1.5°C) are assumed globally, and therefore, the marginal abatement costs (carbon prices) are uniform worldwide and slightly lower than those in the "High Growth Scenario." Although the "Risk Strategy Scenario" assumes that technological progress remains at the current pace, it does not assume emissions constraints but fixed carbon prices. Consequently, energy and electricity costs remain at levels similar to those in the "High Growth Scenario."

Table 2 Marginal abatement costs of CO_2 emissions

	High growth		Renewables		Hydrogen		CCS		Low growth		Risk strategy	
	2040	2050	2040	2050	2040	2050	2040	2050	2040	2050	2040	2050
Japan	301	578	369	716	467	742	396	892	538	951	257	500
US	294	262	350	348	409	454	362	350	410	467	257	500
UK	294	317	350	387	419	558	369	452	428	579	257	500
EU	298	413	350	516	409	648	362	541	410	664	257	500
Others	294	262	350	348	409	454	362	350	410	467	257	500

Unit: USD/tCO_2 (in 2000 price)
Note) Some selected countries are shown.

Table 3 shows the economic impact on Japan. Even in the "High Growth Scenario," which assumes rapid technological advancement, GDP losses are expected to be 4.1% in 2040 and 5.6% in 2050 because of high carbon prices shown in Table 2. The projected declines in the iron and steel sector are -3.9% in 2040 and -11% in 2050 (for example, crude steel production, estimated at 90 million tons/year in 2050, would fall to 80 million tons/year with an 11% decrease). However, if the world works toward the 1.5°C target, there is the possibility of acquiring overseas markets particularly of emissions reduction products, and around 5% growth is expected, although the estimates include large uncertainty. Therefore, this scenario could achieve the same level of economic growth (slightly higher in 2040) as the potential growth projection (estimated at 1.5%/year from 2023 to 2040, considering population decline).

In the "Low Growth Scenario," where technological improvement is incremental, Japan's access to low-cost decarbonized energy is more limited compared to other countries. Consequently, the relative energy price gaps would be widened, which would possibly accelerate the relocation of industries abroad. In the iron and steel and the chemical industries, production is projected to hugely decline by around 40% compared to the baseline. A similar level of decline is also estimated in the automobile (transport machinery) sector. Overall GDP is expected to fall significantly, by around 13–14%. If emissions reduction toward 2050 CN is pursued in a linear manner without major technological improvements, the world of "Low Growth Scenario" shown in the analysis results is quite plausible. To avoid this, the "Risk Strategy Scenario" has been proposed.

Table 3 Changes in production and GDP

Reduction ratios in productions/value added	High growth (DEARS)		Low growth (price elasticity: -1.0, income elasticity: +1.0, and RAS)		Risk strategy (DEARS)	
	2040	2050	2040	2050	2040	2050
Iron and steel	-3.9%	-11.0%	-41%	-46%	-3.6%	-11.0%
(production [million ton/yr])	(86)	(80)	(53)	(49)	—	—
Chemical	-3.7%	-11.2%	-35%	-40%	-3.3%	-10.7%
Non-metal materials	-2.1%	-2.7%	-30%	-34%	-1.7%	-3.8%
Non-steel metals	-1.4%	-2.7%	-35%	-39%	-1.2%	-5.0%
Paper and pulp	-3.5%	-6.3%	-33%	-37%	-3.1%	-7.2%
Transport machinery	-4.1%	-6.9%	-42%	-47%	-4.7%	-8.2%
GDP (excluding the overseas diffusion effects)	-4.1%	-5.6%	-13%	-14%	-3.6%	-5.9%
GDP/GNI (including the oversea diffusions particularly of emission reduction technologies/products	Approximately same of the potential economic growth (oversea effects:+4% to +5%)		Less expectation on the overseas additional effects of economic increase		Approximately same of the potential economic growth (oversea effects:+3% to +4%)	
Annual growth in GDP/GNI since 2023 (note: +1.4% and +1.3%/yr by 2040 and 2040-50, respectively, in baseline)	+1.5%/yr	+1.2%/yr	+0.6%/yr	+0.7%/yr	+1.4%/yr	+1.2%/yr

In the "Risk Strategy Scenario," technological progress is assumed to be not rapid like in the "High Growth Scenario," but as modest as in the "Low Growth Scenario." As a result, although emissions are higher (a 61% reduction in 2040 and 79% in 2050), the economic impacts are estimated to be around the same as in the "High Growth Scenario." A sharp decline in economic activities and the relocation of industries due to carbon constraints should be avoided, and this scenario is for addressing such risks.

4.2. Energy demand and supply

Figure 4 shows Japan's primary energy supply. In all the scenarios, a substantial reduction is observed in 2040 and 2050. The expansion of renewables and the use of CCS are considered economically efficient. The import of hydrogen, ammonia, e-methane, and e-fuels is also evaluated as cost-effective. Both primary energy supply and electricity generation are significantly constrained in the "Low Growth Scenario." On the other hand, in the "Risk Strategy Scenario," the import of hydrogen-based energy is reduced, and maintaining the current level of LNG use will be economically efficient.

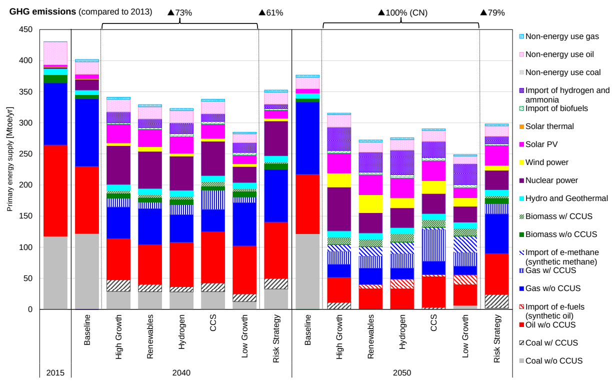

Figure 4 Primary energy supply in Japan

Figure 5 shows final energy consumption in Japan. Raising the electrification ratio is an economically reasonable measure, and a significant reduction in final energy consumption will be required. On the other hand, in the industry, residential, and transport sectors, full electrification will not be economically efficient, and measures combining with hydrogen, ammonia, e-methane, e-fuels, and bio fuels will be cost-efficient. The electrification ratio in the total of final energy consumption is estimated to be 38-44% in the 73% reduction by 2040 scenario, and 54-57% at the point of CN in 2050.

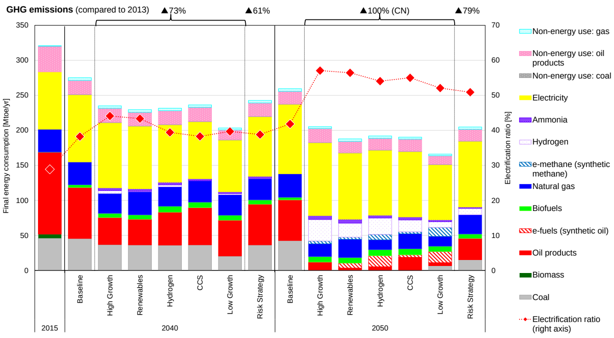

Figure 5 Final energy consumption in Japan

Electricity supply (Figure 6) is expected to potentially increase due to IT demand and others, however, if relative energy prices remain high, energy consumption may need to be suppressed along with production decrease caused by industry shift overseas. Since economically viable power generation investments often require long lead times, it is critical to implement energy and climate policies with high predictability to avoid electricity shortages and prevent the realization of the "Low Growth Scenario."

Regarding LNG-based power generation (including cogeneration and facilities with CCS) in the "Risk Strategy Scenario," the result shows that sustaining them at about current level through 2050 will be cost-efficient.

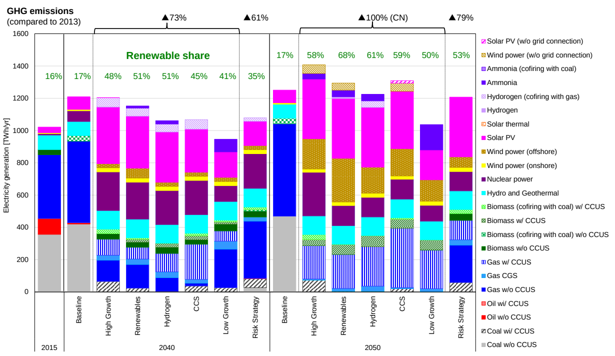

Figure 6 Electricity supply in Japan

Figure 7 shows final electricity consumption by sector. In all the scenarios, electricity demand is expected to increase toward 2040, and grow even further toward 2050 due to increasing IT and electrification demands. Electricity demand is projected to be 1,081 TWh/year in 2040 and 1,210 TWh/year in 2050 under the "High Growth Scenario." For 2040, relatively higher CO_2 marginal abatement costs in the "Hydrogen Scenario" and the "CCS Scenario than those in other scenarios will lead to lower electricity demands. In the "Low Growth Scenario," high energy prices are expected to significantly suppress electricity demand.

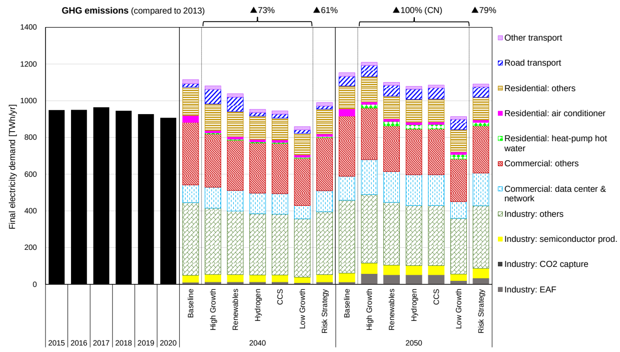

Figure 7 Final electricity consumption in Japan

Figures 8 and 9 show the CO_2 and hydrogen balances in Japan, respectively. In 2050, Direct Air Carbon Capture and Storage (DACCS) is regarded as an economically viable measure in many scenarios. Hydrogen imports are evaluated as cost-effective, with diverse applications projected in the power generation, the iron and steel, and other sectors. In addition to direct hydrogen use, the import and use of ammonia, e-methane, and e-fuels are also evaluated as economically efficient, as mentioned earlier.

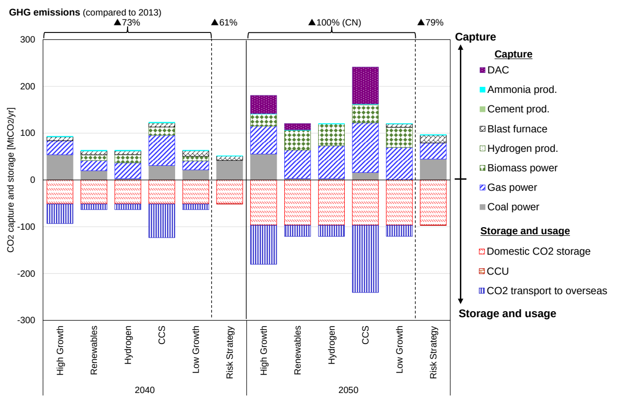

Figure 8 CO_2 balance in Japan

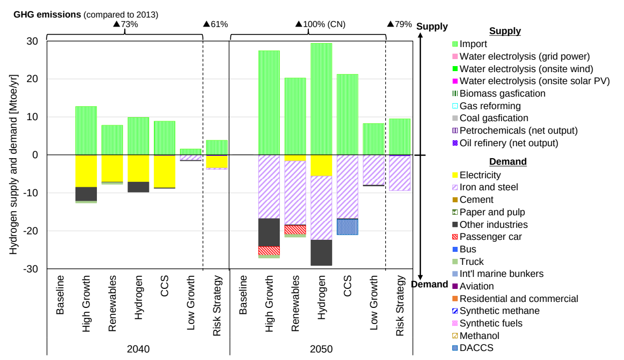

Figure 9 H_2 balance in Japan

5. Summary and policy implications

RITE conducted energy system analyses for Japan toward the 2050 CN target assuming multiple scenarios, using global models such as DNE21+ and DEARS, which provide results balancing energy supply and demand and costs. To achieve a virtuous cycle between the economic growth and the environment, it is crucial to focus on the relative energy prices gaps with other countries, and the analyses were conducted considering that.

While the world has been taking actions toward ambitious goals such as 1.5°C and 2050 CN, significant gaps with current emissions are observed. Even in countries including Japan, where emissions reduction has progressed considerably, there are the cases that the emissions reduction is mainly attributed to the decline in production in energy-intensive industries and the relocation of manufacturing abroad. The "High Growth Scenario" is the optimum situation, however, climate change requires global actions, and effective solutions cannot be achieved without international cooperation. It is also important to recognize that the "High Growth Scenario" represents a narrow pathway and to prepare energy strategies that account for the potential emerging risks of the "Low Growth Scenario."

These analyses conducted by RITE were a major source of reference for formulating the energy demand and supply outlook in the 7th Strategic Energy Plan. It can be said that the 7th Strategy Energy Plan provides a strategy for achieving CN while also considering energy supply stability and economic viability, by presenting multiple scenarios, including the "Risk Strategy Scenario" for risk management.

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