Discussion Paper

(Excerpted version) Study on Climate-related Scenario Analysis: Characteristics of NGFS Scenarios and their Applications in Climate-related Financial Risk Analysis

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Study on Climate-related Scenario Analysis: Characteristics of NGFS Scenarios and their Applications in Climate-related Financial Risk Analysis

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4. Characteristics of the NGFS Scenarios (Phase 2) Identified through Comparison of Key Variables

Scenarios used in the context of financial risk analysis related to climate change are quantified through a combination of multiple quantitative models, including integrated assessment models (IAMs) and climate models, based on narratives that qualitatively describe economic, social and technological developments. The outcomes obtained through the quantification may vary under the same narrative depending on the detailed assumptions adopted and the structures, solutions, and economic expressions of the models applied. The NGFS scenarios (Phase 2) seeks to capture a range of future uncertainties by using three IAMs for the purpose of quantification (NGFS, 2021a,b).

This chapter identifies the characteristics of scenarios by focusing on key variables related to transition risks in the NGFS Scenarios (Phase 2). Specifically, the variables to be analyzed are CO_2 emissions, CO_2 removal, carbon prices, primary energy, secondary energy (electricity generation), final energy, energy prices (fossil fuel and electricity prices), and energy-related capital cost and investment.

4.1 identifies the characteristics of the quantified variables at the global level and provides an overview of the characteristics of the NGFS Scenarios (Phase 2). 4.2 identifies the quantified variables regarding Japan and analyzes the characteristics specific to Japan through comparison with global trends. 4.3 analyzes the region-specific characteristics through comparison of the variables across major regions around the world (advanced and emerging economies). The analysis will refer to differences between the quantification processes of the three adopted IAMs, the range of plausible uncertainties, and the validity of quantification results as necessary.

4.4 compares the calculation results obtained from major existing scenarios with respect to the world and Japan in order to identify the characteristics of the quantification in the NGFS Scenarios (Phase 2). As was already mentioned, in the NGFS scenarios, three IAMs are used for the quantification purpose in order to capture a range of future uncertainties. On the other hand, in the field of climate change, there is a vast accumulation of scenario analysis results and also results of quantification using many IAMs other than the three adopted by the NGFS and non-IAM approaches. Through comparison of those results with the NGFS Scenarios (Phase 2), we verify the adequacy of the quantification results obtained through the three IAMs adopted by the NGFS.

4.1 Overview of the NGFS Scenarios (Phase 2): Global Scenarios

4.1.1 CO_2 Emissions

Scenario characteristics common across the IAMs

Net Zero 2050 and Divergent Net Zero: These two scenarios assume early introduction of ambitious emission reduction policies ("policy ambition" is "1.5°C" and "policy reaction" is "immediate"). Under the scenarios, the pace of CO_2 emission reduction is faster than under the other four scenarios, with net emissions projected to be reduced to almost zero in 2050 (Figure 4.1.1●●).

Below 2ºC and Delayed transition: While both of these two scenarios assume introduction of medium-level emission reduction policies, they are different in the timing of introduction ("policy ambition" is "1.7°C" to "1.8°C" in both cases and "policy reaction" is "immediate" in the case of "Below 2ºC" and "delayed" in the case of "Delayed transition"). Emissions will be reduced towards 2050 under both scenarios, but "under the "Delayed transition" scenario, emissions will continue increasing until 2030, to be followed by a rapid fall thereafter (Figure 4.1.1● ●).

NDCs and Current Policies: These two scenarios assume implementation of current policies or their equivalents ("policy ambition" is "2.5°C to "3°C+" in 2100 in both cases and "policy reaction" is "NDCs" in the case of "NDCs" [in accordance with national goals; however, limited to NDCs submitted by December 2020] and "None" in the case of "Current Policies"). CO_2 emissions will decrease slightly or increase towards 2050. The emission reduction rate under the NDCs scenario is below the level required for achieving the 1.5º goal (Net Zero 2050) and the below 2ºC goal (Below 2 ºC)[1] (Figure 4.1.1●●).

Differences between the IAMs

The relative scales of CO_2 emissions between the scenarios are mostly consistent across the IAMs, but there are slight disparities in terms of the absolute volume of CO_2 emissions. However, given the uncertainty over the relationship between emissions of CO_2 and other greenhouse gases (GHGs) and a temperature rise, the slight disparities in the emission volume probabilistically have little impact on the level of temperature rise.

[1] However, as countries update their climate change policies annually in line with the increasing ambition toward mitigating climate change in the international community, it should be kept in mind that policies assumed in scenarios in the NGFS Scenarios (Phase 2) are not necessarily equivalent to the most up-to-date policies at the time of scenario development or analysis.

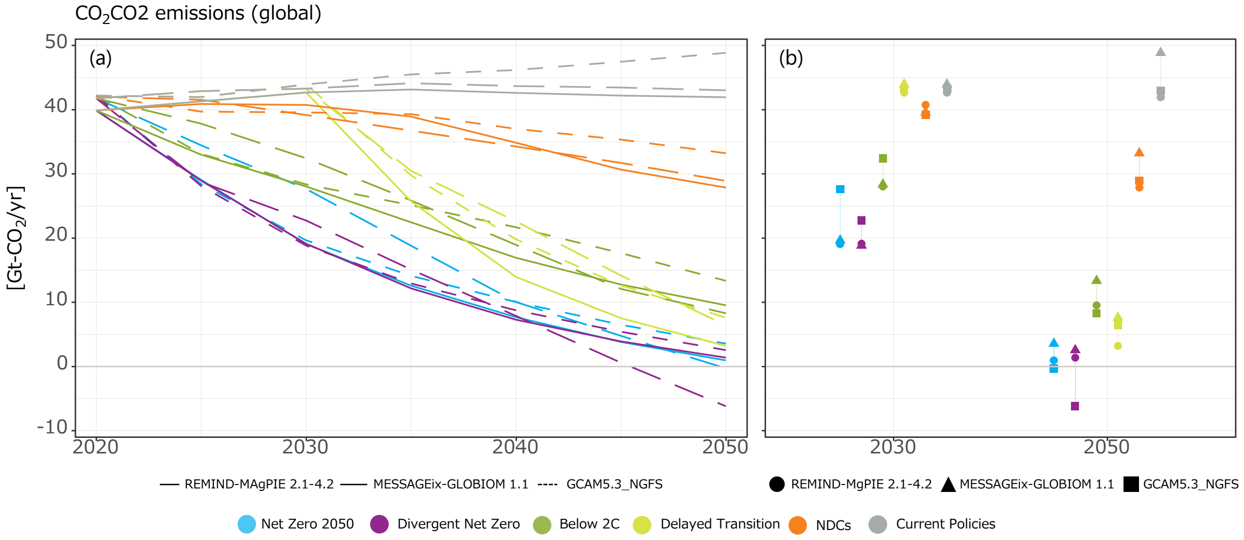

Figure 4.1.1 Pathways of global CO_2 emissions (a) and volumes of emissions in 2030 and 2050 (b)

4.1.2 Carbon Prices

According to the Technical Documentation regarding the NGFS Scenarios (Phase 2), carbon pricing will have economy-wide effects as a main policy tool[2] under all of the six scenarios (NGFS, 2021a). Carbon prices are calculated region by region under the IAMs in accordance with the emission reduction levels necessary for achieving the temperature targets imposed by the scenarios.[3] The global carbon price represents the figure obtained by averaging regional carbon prices weighted by emissions.

As the carbon price calculation depends on the formulation used within each IAM, the underlying assumption is generally different in nature from the carbon tax and emissions trade systems that have been introduced as actual policy tools. Prices calculated through the IAMs adopted under the NGFS scenarios are rather an indicator of the intensity of economy-wide emission reduction policies set within the IAMs based on the gap between the existing level of emissions and the policy goal.

However, in the NGFS Scenarios (Phase 2), the macroeconomic impact is calculated through the NiGEM model based on the carbon price calculated through each IAM. In other words, carbon prices in the NGFS Scenarios (Phase 2) may indicate the level of transition risk under the emission reduction policy assumed in each scenario.

<u>Scenario characteristics common across the IAMs</u>

Looking at the trends in the six scenarios, it is clear that the uptrend in carbon prices in the period through 2050 is stronger in scenarios with more ambitious policy reduction policies.

Net Zero 2050 (1.5ºC): As a result of early introduction of ambitious emission reduction policies ("policy reaction" is "immediate"), carbon prices will rise towards 2050 (Figure 4.1.2(b)●).

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[2] The NDCs and Current Policies scenarios assume the implementation of current emission reduction policies in addition to carbon pricing.
[3] In the Divergent Net Zero scenario, although carbon prices are treated as an exogenous variable, they are still consistent with the prescribed level of emissions reduction.

Divergent Net Zero (1.5ºC): As ambitious emission reduction policies are introduced early albeit with divergence in policy intensity across sectors ("policy reaction" is "immediate but "divergent" across sectors), carbon prices will be at a high level in 2020 and 2050 compared with the Net Zero 2050 scenario (Figure 4.1.2(b)●).

As "disorderly" emission reduction policies (divergent in policy intensity across sectors) are put into practice, the additional impact from the cross-sectoral divergence is expressed by setting the carbon price for emissions from the transport sector and the consumer sector at triple the level for emissions from other sectors based on the carbon price in the Net Zero 2050 scenario.

Below 2ºC (1.7ºC): As a result of emission reduction policies with a medium level of ambition, the margin of increase in carbon prices in 2030 and in 2050 will be smaller than under the Net Zero 2050 scenario (Figure 4.1.2(b)●).

Delayed Transition (1.8ºC): While the ambition of the emission reduction policy is at a medium level, the policy will not be introduced until 2030 ("policy reaction" is "delayed"). Carbon prices in 2030 will be almost zero, but under the MESSAGEix-GLOBIOM 1.1and GCAM 5.3 models, prices in 2050 will be higher than in the Net Zero 2050 scenario (Figure 4.1.2(b)●).

NDCs（2.5ºC） and Current Policies● (3ºC+): As a result of emission reduction policies equivalent to the current policies (2.5ºC to 3ºC+), carbon prices in 2030 and 2050 will be at or near zero (Figure 4.1.2(b)●●).

<u>Differences between the IAMs</u>

With respect to the Net Zero 2050 (1.5ºC), Divergent Net Zero (1.5ºC) and Delayed Transition (1.8ºC) scenarios, the relative levels of carbon prices between the scenarios in 2050 differ across the IAMs (Figure 4.1.2(b)). While this is presumably due to differences in the economic expressions, solutions and emissions pathways of the IAMs and , it indicates that the relationship between the scenario narrative and carbon prices is not necessarily a one-to-one correspondence. It should be kept in mind that if carbon prices are considered to be an indicator of the intensity of emission reduction policies or the degree of transition risk, the relationship between the scenario narrative and carbon prices under the above three scenarios may vary across the IAMs.

REMIND-MAgPIE 2.1-4.2: Divergent Net Zero● (1.5ºC) > Net Zero 2050● (1.5ºC) > Delayed Transition● (1.8ºC)

MESSAGEix-GLOBIOM 1.1: Delayed Transition▲ (1.8ºC) > Divergent Net Zero▲ (1.5ºC) > Net Zero 2050▲ (1.5ºC)

GCAM 5.3: Divergent Net Zero■ (1.5ºC) >> Delayed Transition■ (1.8ºC) > Net Zero 2050■ (1.5ºC)

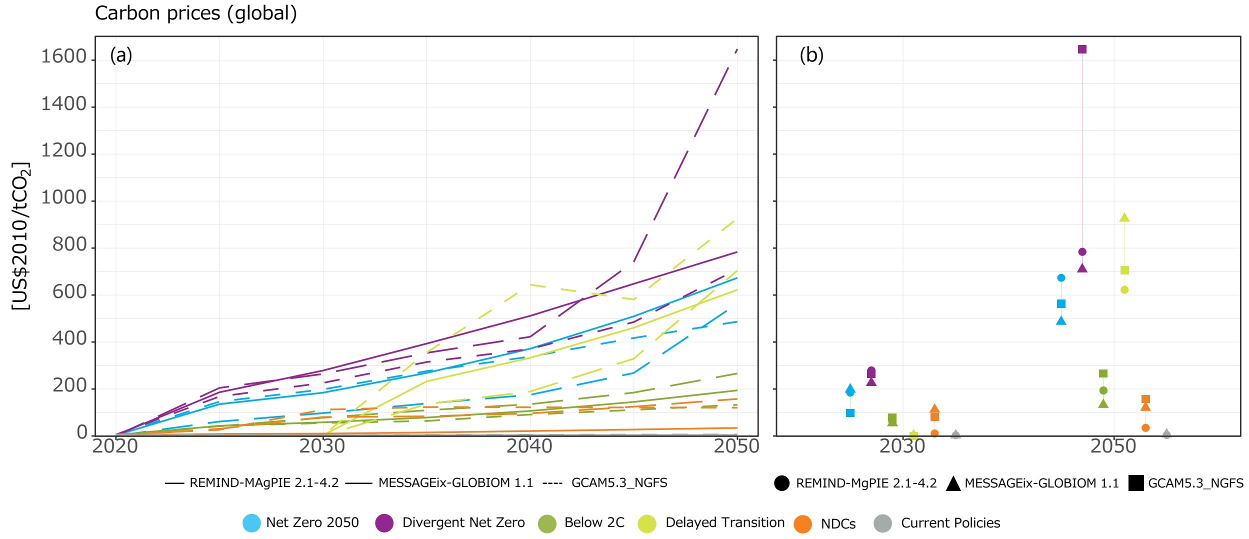


Figure 4.1.2 Pathways of global carbon prices (a) and carbon prices in 2030 and 2050 (b)

4.1.3 CO_2 Emissions by Sector

Within each IAM, activity volume and volume of emissions from activity by sector are calculated under constraints, such as emission reduction policies, technology and cost, with respect to each of energy consumption (see 4.1.5, 4.1.6, and 4.1.8) and land use. Therefore, the reduction of CO_2 emissions does not necessarily proceed in similar ways across all sectors.

<u>**Scenario characteristics common across the IAMs**</u>

The more intense the emission policy reduction is, the closer to zero CO_2 emissions will approach in 2050 (Figure 4.1.3). However, the residual emissions from the transport sector■ in particular tend to be higher than emissions from other sectors (Figure 4.1.3 (a)(b)). On the other hand, emissions from the energy supply sector (electricity■ and others■) and the AFOLU■ (land use)[4] will become negative (i.e., CO_2 removals will exceed emissions) in some scenarios (Figure 4.1.3 (a) to (c)).

Net Zero 2050 and Divergent Net Zero (1.5°C): CO_2 emissions from the transport sector■ in 2050 will be minimized, while emissions from the energy supply sector (electricity■ and others■) and the AFOLU■ (land use) will be close to zero or negative (Figure 4.1.3(a)(b)).

Below 2°C and Delayed Transition (1.7°C to 1.8°C): CO_2 emissions from the transport sector■ in 2050 will be at a medium level, while emissions from the energy supply sector (electricity■ and others■) and the AFOLU■ (land use) will be close to zero or negative in many cases (Figure 4.1.3(c)(d)).

NDCs and Current Policies (2.5°C to 3°C+): In 2050, there will be residual CO_2 emissions in all sectors except for the AFOLU sector■ (land use) (Figure 4.1.3(e)(f)).

[4] AFOLU stands for Agriculture, Forestry and Other Land Use (see the glossary of Technical Documentation (NGFS, 2021a)).

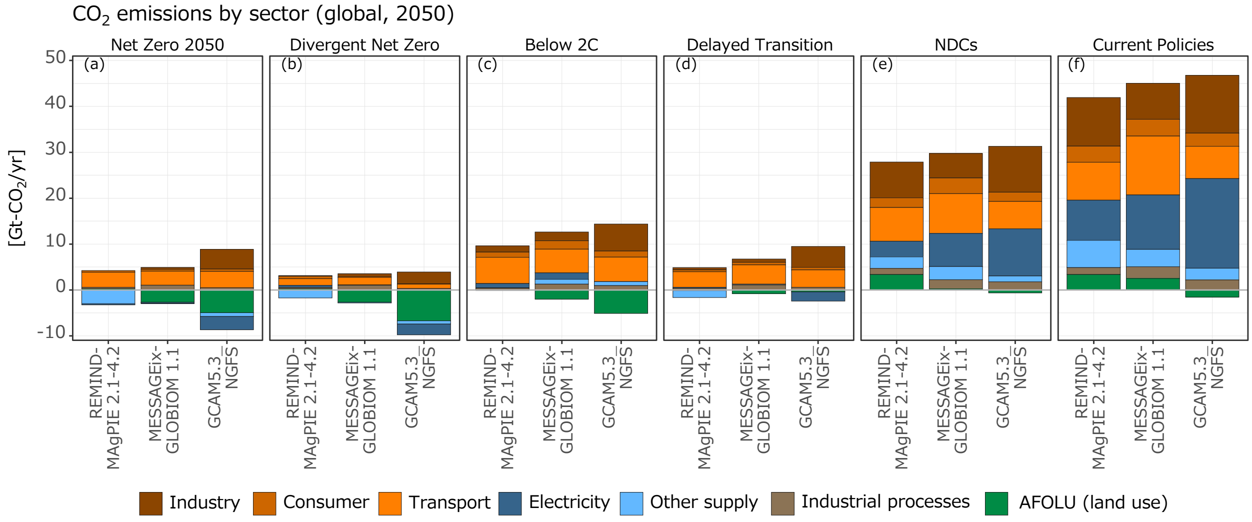


Figure 4.1.3 CO_2 emissions by sector[5] in 2050 (global)

<u>Differences between the IAMs</u>

There is no significant difference across the IAMs in terms of overall emissions (Figure 4.1.1). However, regarding emissions in 2050 (Figure 4.1.3) and emission pathways in the period through 2050 (Figure 4.1.4), there are differences within scenarios and between the IAMs. This is presumably because the assumptions of sector-by-sector cost of emission reduction technology and cost of CO_2 removal technology vary across the IAMs.

There are significant differences between the IAMs in terms of CO_2 emissions from the industrial sector in 2020 (Figure 4.1.4(a)). As a result, significant differences will remain between the IAMs in 2030 and 2050. In 2030 in particular, the differences between the IAMs will be larger than those between the scenarios (Figure 4.1.4(h)). In the energy supply sector (electricity and other supply), emissions in 2050 will be almost zero or negative under the Below 2ºC scenario. However, according to Figure 4.1.3(a) to (d), the relative sizes of emissions from the electricity ■ and emissions from other supply■ (energy supply other than electricity) sectors vary across the IAMs.

In the Net Zero 2050 scenario, which assumes the introduction of the most ambitious emission reduction policy, there are some characteristics specific to the respective IAMs with regard to the combination of sectors where there will be residual emissions in 2050 and sectors that offset the residual emissions and the level of residual emissions.

REMIND-MAgPIE 2.1-4.2: In the energy supply sector, the volume of emissions from other supply (energy supply other than electricity) will become negative (Figure 4.1.3(a)■ and Figure 4.1.4(l)●), offsetting the residual emissions from the transport sector (Figure 4.1.3(a)■).

MESSAGEix-GLOBIOM 1.1: While emissions from the energy supply sector will be almost zero (Figure 4.1.4(k)(l)▲), emissions from the AFOLU sector (land use) (Figure 4.1.3(a)■) will become negative, offsetting the residual emissions from the transport sector (Figure 4.1.3(a)■).

GCAM 5.3: Both the volume of residual emissions in 2050 and the volume of offsetting negative emissions are the largest

[5] Emissions from "industrial processes" are those from processes other than fuel combustion, such as cement production. Emissions from all other sectors except for AFOLU (land use) are due to fossil fuel combustion.

of the three IAMs (Figure 4.1.3(a)). In the energy supply sector, CO_2 emissions from electricity will become negative (Figure 4.1.3(a)■ and Figure 4.1.4(k)■), and the volume of negative emissions in the AFOLU sector (land use) will also be large (Figure 4.1.3(a)■ and Figure 4.1.4(n)■). As overall emission removals are large, emissions from the industrial sector are positive (Figure 4.1.3(a)■ and Figure 4.1.4(h)■).

In the Current Policies scenario, which does not assume the introduction of emission reduction policies, there are also sector-by-sector differences in emissions, reflecting the characteristics of the respective IAMs.

REMIND-MAgPIE 2.1-4.2: In the energy supply sector, the volume of emissions from electricity will be small compared with the other IAMs and decline between 2030 and 2050 (Figure 4.1.3(f)■ and Figure 4.1.4 (k)●). This is presumably due to an increase in the share of renewable energy (solar and wind power) in electricity generation (secondary energy) in 2050 (4.1.6). On the other hand, the volume of emissions from the AFOLU sector is the largest (Figure 4.13 (f)■ and Figure 4.1.4 (n)■).

MESSAGEix-GLOBIOM 1.1: In the energy demand sector, the volume of emissions from transport is large compared with the other IAMs and will increase between 2030 and 2050 (Figure 4.1.3(f)■ and Figure 4.1.4(j)▲). On the other hand, although the volume of emissions in the industrial sector will increase toward 2050, it will be smaller than the volumes of emissions under the other IAMs (Figure 4.1.3(f)■ and Figure 4.1.4(j)▲).

GCAM 5.3: The volumes of emissions from industry in the energy demand sector and emissions in the energy supply sector are large compared with the other IAMs (Figure 4.1.3(f)■ and Figure 4.1.4(k)■). This is presumably because the shares of coal and natural gas without CCS in electricity generation (secondary energy) will remain high in 2050 (0 and Figure 4.1.9(f)). On the other hand, emissions from the AFOLU sector (land use) will become negative (Figure 4.1.3(f)■ and Figure 4.1.4(n)■).

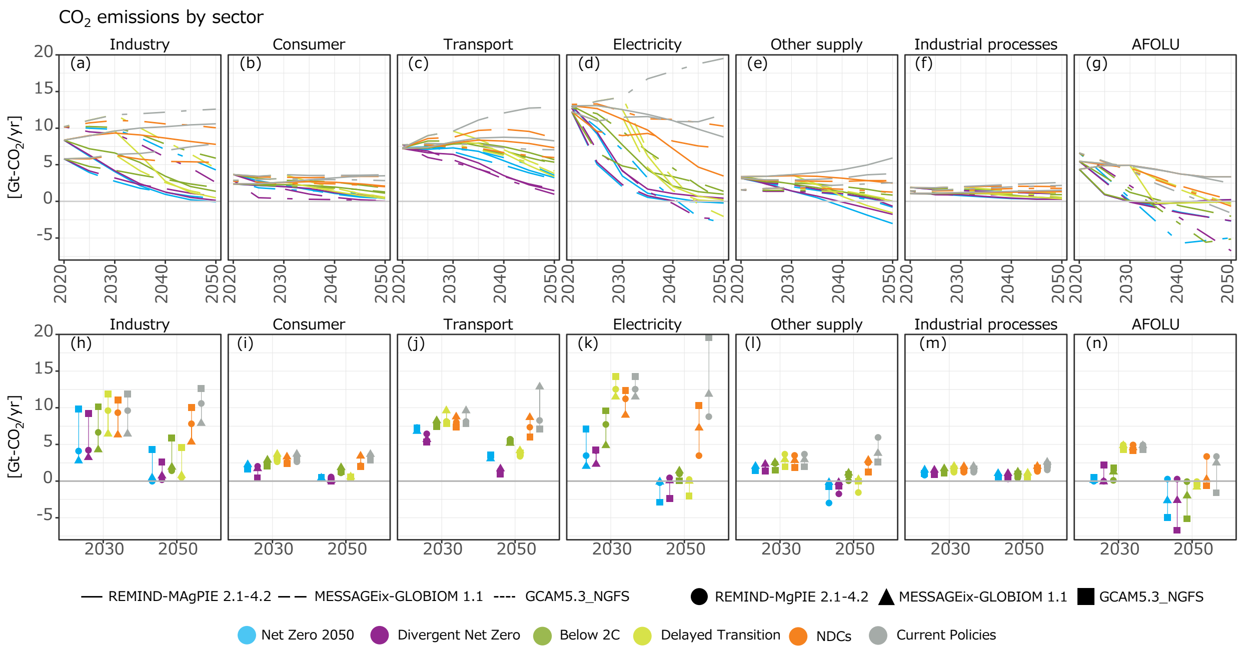


Figure 4.1.4 Temporal changes in CO_2 emissions by sector (upper row) and volumes of emissions in 2030 and 2050 (lower row)

4.1.4 CO_2 Removals

In the sectors where CO_2 emissions will become negative as shown in 0, some sort of CO_2 removal technology will be introduced. The previous sections looked at CO_2 emissions on a net basis, with the volume of CO_2 removals deducted from the volume of CO_2 emissions. This section focuses on gross CO_2 removals (volume of CO_2 sequestered in soil before being absorbed into the atmosphere).

Regarding CO_2 removal technology, BECCS (bioenergy with carbon capture and storage) in the energy supply sector will play a significant role. In the NGFS scenarios, CO_2 removal technology is assumed to be introduced in the electricity sector (bioenergy-based electricity generation) and the non-electricity energy supply sector (production of biofuels and hydrogen). Afforestation in the AFOLU sector (land use) is also considered to be equivalent to CO_2 removal technology.

The NGFS Scenarios (Phase 2) reported on the volume of CO_2 removals due to BECCS in the energy supply sector and afforestation in the AFOLU sector (land use). On the other hand, CO_2 removals due to direct air carbon dioxide capture and storage (DACCS) were not included in the report's data.

<u>**Scenario characteristics common across the IAMs**</u>

The volume of CO_2 removals is almost zero in 2020 and will increase towards 2050 in accordance with the level of ambition of the respective emission reduction policies introduced under the scenarios. In particular, the volume of CO_2 removals due to BECCS varies significantly across the scenarios.

Net Zero 2050 (1.5ºC): CO_2 removals due to BECCS will increase. The volume of total CO_2 removals in 2050 will be the largest of all scenarios. The volume of CO_2 removals due to BECCS is large compared with other scenarios (Figure 4.1.5(a)■■■■).

Divergent Net Zero (1.5ºC): Although CO_2 removals due to BECCS will increase, the volume of CO_2 removals in 2050 will be slightly smaller than in the Net Zero 2050 scenario (Figure 4.1.5(b)■■■■).

Below 2ºC (1.7ºC): Although CO_2 removals due to BECCS will increase, the volume of CO_2 removals due to BECCS in 2050 will be smaller than in the Net Zero 2050 and the Divergent Net Zero scenarios (Figure 4.1.5(c)■■■■).

Delayed Transition (1.8ºC): As CO_2 removals due to BECCS will increase rapidly from 2030 onwards, the volume of CO_2 removals in 2050 will be larger than in the Below 2ºC scenario and close to the levels in the Net Zero 2050 and Divergent Net Zero scenarios (Figure 4.1.5(d)■■■■).

NDCs and Current Policies (2.5ºC to 3ºC+): The volume of CO_2 removals due to BECCS will be smaller than in the other four scenarios. In particular, in the Current Policies scenario, the volume of CO2 removals due to BECCS will be almost zero across all IAMs (Figure 4.1.5(f)).

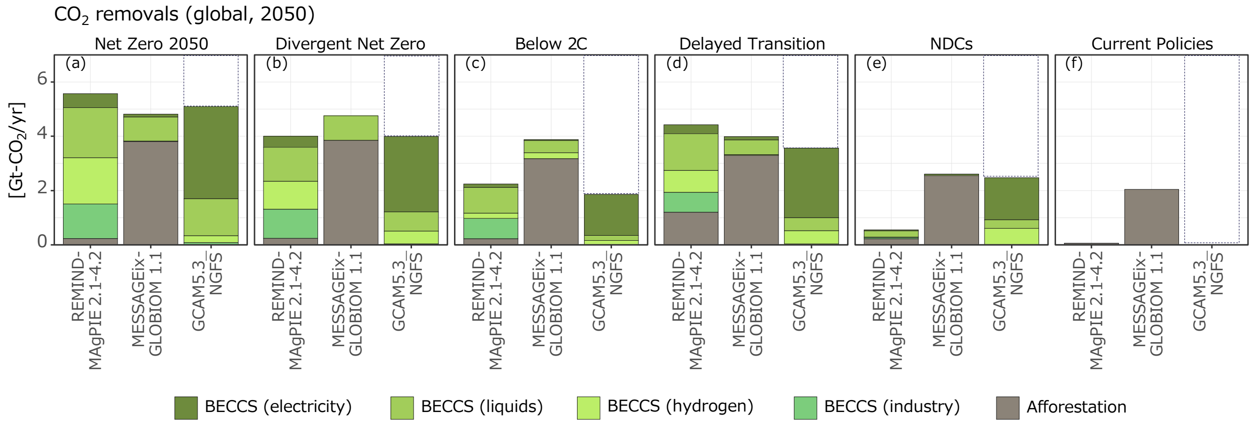


Figure 4.1.5 CO_2 removal capacity introduced in 2050 and the breakdown by type of technology (the figures represent the total sum of the values obtained within the IAMs, but the actual total volume for GCAM 5.3 is presumed to be larger given the absence of data on removals due to afforestation).

Differences between the IAMs

While the assumptions of the cost and efficiency of CO_2 removal technologies differ across the IAMs, there are characteristics common across the scenarios with respect to sectors where technology is deployed and the volume of CO_2 removals due to the technology deployment (Figure 4.1.5, Figure 4.1.6).

REMIND-MAgPIE 2.1-4.2: In scenarios that assume the deployment of emission reduction technology (Figure 4.1.5(a)-(d) and Figure 4.1.6●●●●), the volumes of CO_2 removals due to BECCS (liquids) (Figure 4.1.5■ and Figure 4.1.6(b)(g)), BECCS (hydrogen) (Figure 4.1.5■ and Figure 4.1.6(c)(h)), and BECCS (industry) (Figure 4.1.5■and Figure 4.1.6(d)(i)) under this IAM are large compared with the other IAMs. On the other hand, the volume of CO_2 removals in 2050 will be almost zero in the NDCs and Current Policies scenarios (Figure 4.1.5(e)(f)). In short, the volume of CO_2 removal varies widely across the scenarios.

MESSAGEix-GLOBIOM 1.1: Towards 2050, the volume of CO_2 removals due to afforestation will increase significantly (Figure 4.1.6(e)(j)▲), and the volume of CO_2 removals in 2050 will not vary significantly across the scenarios (Figure 4.1.5■ and Figure 4.1.6(e)(j)▲). On the other hand, the volume of CO_2 removals due to BECCS in most scenarios and in most sectors will be smaller than those under the other IAMs (Figure 4.1.6(a)-(d), (f)-(i)).

GCAM 5.3: In many scenarios, the volume of CO_2 removals due to BECCS (electricity generation) is large (Figure 4.1.5■ and Figure 4.1.6(a)(f)).

Under GCAM 5.3, CO_2 removals due to afforestation is not reported, but the volume of removals is presumed to be larger than those under the other IAMs (in Figure 4.1.3(a)(b), the volume of negative emissions [negative net emissions, i.e., emissions minus removals] in the AFOLU sector■ is larger than that under MESSAGEix-GLOBIOM 1.1, and this is presumably due to CO_2 removals due to afforestation). Therefore, the overall volume of CO_2 removals is also presumed to be larger than those under the other IAMs.

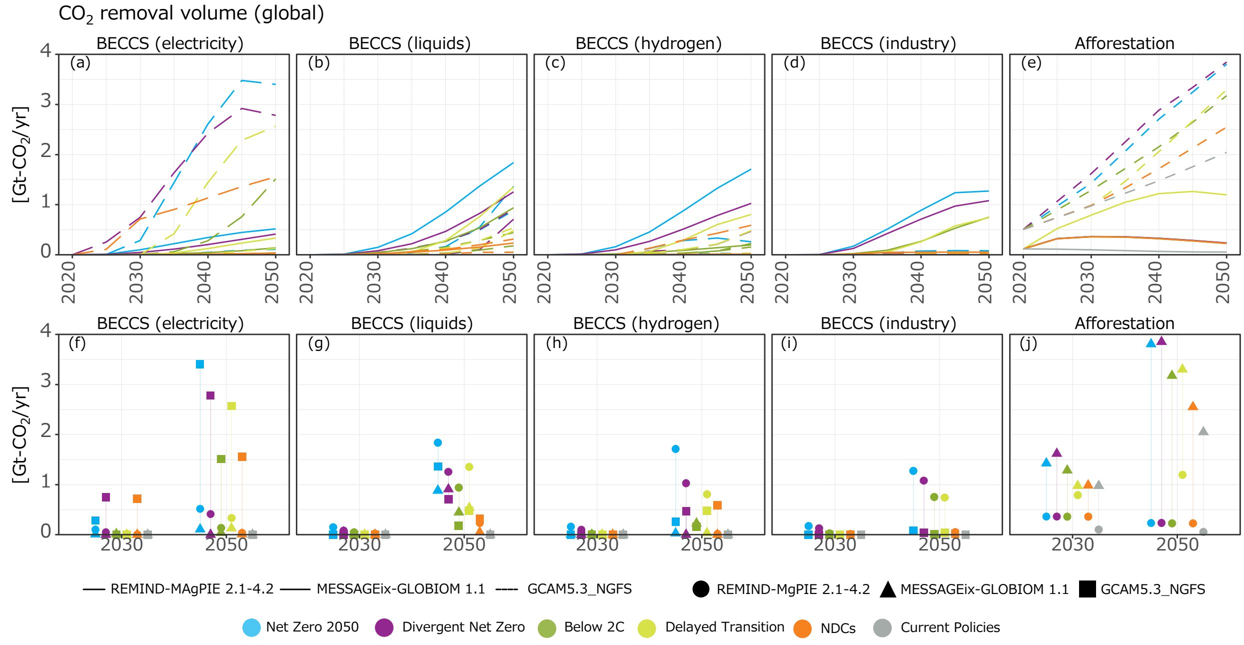


Figure 4.1.6 Pathways of CO_2 removals by sector (upper row) and removal volumes in 2030 and 2050 (lower row)

4.1.5 Primary Energy

Primary energy on which the NGFS Scenarios (Phase 2) reported includes both fossil fuels and non-fossil ones, i.e., renewable energy and nuclear power.

With regard to fossil fuels, the total sum of energy consumed directly as fossil fuels and energy consumed as secondary energy, such as electricity and heat, is reported in terms of energy equivalents (EJ). Fossil fuels are categorized into coal, natural gas and oil, and those consumed for power generation are further categorized into those with or without CCS. Fossil fuel consumption involving CO_2 emissions is fossil fuel consumption without CCS. Fossil fuel consumption without CCS represents the energy-derived portion of the CO_2 emissions that were analyzed in the previous sections.

On the other hand, renewable energy is categorized into biomass-derived and non-biomass-derived (including hydro, wind, geothermal, photovoltaic, and solar heat).

Scenario characteristics common across the IAMs

According to a comparison between the four scenarios that assumes the introduction of emission reduction policies with a temperature rise target of below 2ºC or lesser (Figure 4.1.7(a)-(d)) and the scenarios that do not (NDCs and Current Policies; Figure 4.1.7(e)(f)), the consumption volume of primary energy in 2050 tends to be smaller in the four scenarios than in the others. By sector, emissions from coal without CCS■ will decrease to almost zero by 2050. On the other hand, regarding oil■, there will be some residual consumption in 2050. In short, the divergence in consumption volume across the scenarios is larger for coal than for other fossil fuels (Figure 4.1.8(p); the respective ranges of the scenarios have few overlaps). On the other hand, the consumption volume of renewable energy will increase towards 2050 (Figure 4.1.8(b)(j)).

Net Zero 2050 and Divergent Net Zero (1.5ºC): Volume of renewable energy■□ capacity deployment in 2050 will be the largest. As for fossil fuels without CCS, the consumption volumes of coal■ and natural gas■ will be close to zero, but there will be some residual consumption of oil■ in 2050 (Figure 4.1.7(a)(b)).

Below 2ºC and Delayed Transition (1.7ºC~1.8ºC): As is the case in the Net Zero 2050 and Divergent Net Zero scenarios, the share of renewable energy■□ is large in 2050 while the shares of coal■ and natural gas■ are small. On the other hand, the residual consumption of oil in 2050 will be somewhat larger than in those two scenarios (Figure 4.1.7 (c)(d)).

NDCs and Current Policies (2.5ºC~3ºC+): Volume of renewable energy ■□ capacity deployment will increase towards 2050 but will be smaller than in the above four scenarios. On the other hand, consumption volume of fossil fuels without CCS (coal■, natural gas■, and oil■) will be large.

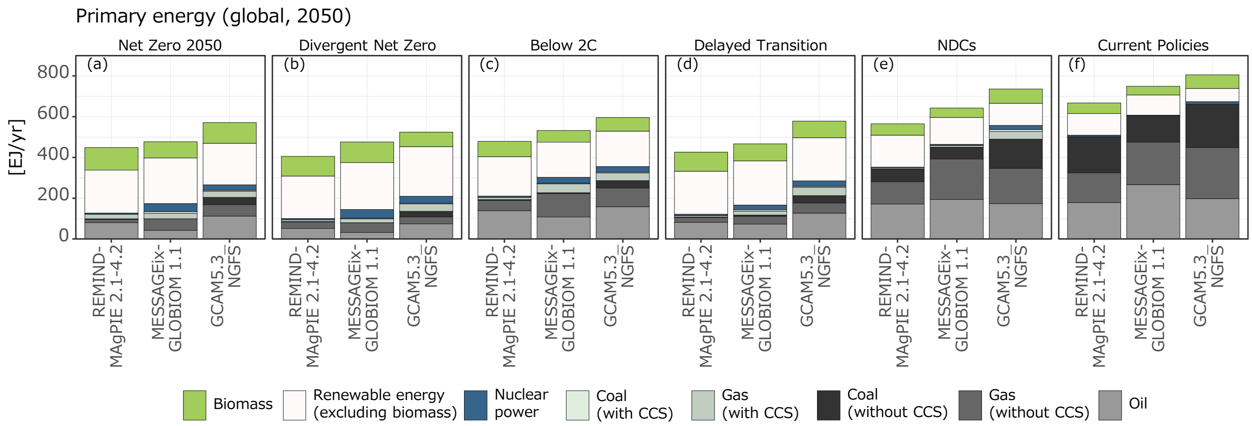


Figure 4.1.7 Primary energy by sector in 2050 (global)

<u>**Differences between the IAMs**</u>

With respect to consumption volumes of primary energy and fossil fuels without CCS, there are some characteristics common across all of the IAMs.

Regarding the Net Zero 2050 scenario, which assumes the introduction of the most ambitious emission reduction policy, consumption volume of fossil fuels without CCS (coal, gas, and oil) will trend downward towards 2050 under all of the IAMs (Figure 4.1.7(a) and Figure 4.1.8(f)-(h)). On the other hand, consumption volume of primary energy will differ across the IAMs (Figure 4.1.8(n)-(p)).

REMIND-MAgPIE 2.1-4.2: Total primary energy consumption in 2050 will be the smallest of the IAMs, while consumption of renewable energy is large (Figure 4.1.7). As for fossil fuels without CCS, consumption of coal will decrease rapidly by 2030 and fall to almost zero in 2050 (Figure 4.1.7■ and Figure 4.1.8(n)●). Consumption of natural gas in 2030 and 2050 will be the smallest (Figure 4.1.7■ and Figure 4.1.8(o)●). In addition, the share of nuclear power will be the smallest (Figure 4.1.7■ and Figure 4.1.8(k)●).

MESSAGEix-GLOBIOM 1.1: Total primary energy consumption in 2050 will be at a medium level (Figure 4.1.7). As for fossil fuels without CCS, consumption of coal will decrease rapidly by 2030 and fall to almost zero in 2050 (Figure 4.1.7■ and Figure 4.1.8(n)▲). Consumption of natural gas in 2030 and 2050 will be at a high level (Figure 4.1.8(o)▲). Although the share of nuclear power in 2050 in overall primary energy consumption under this IAM will be small, it will be the largest of the three IAMs (Figure 4.1.7■ and Figure 4.1.8(k)▲).

GCAM 5.3: Total primary energy consumption in 2050 will be the largest, while consumption of fossil fuels without CCS (coal, gas, and oil) will be larger than under the other IAMs (Figure 4.1.7 and Figure 4.1.8(n-p)■). Although consumption of coal will decrease by around 90% by 2050 under the other IAMs, the consumption under GCAM will fall by only around 50% (Figure 4.1.7■ and Figure 4.1.8(n)■). Consumption of natural gas in 2030 and 2050 will be at a high level (Figure 4.1.8(o)). In addition, consumption of nuclear power will be the second-largest, after the volume under MESSAGEix-GLOBIOM 1.1 (Figure 4.1.7■ and Figure 4.1.8(k)■).

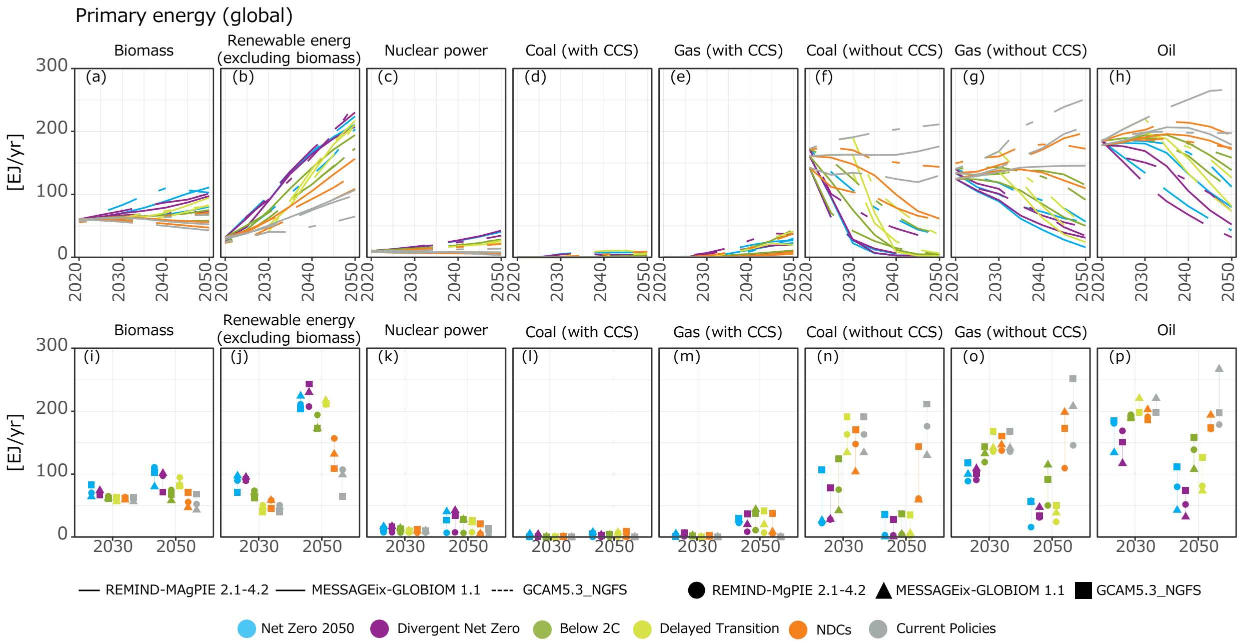


Figure 4.1.8 Pathways of primary energy by sector (upper row) and energy volumes in 2030 and 2050 (lower row)

4.1.6 Secondary Energy (Electricity Generation)

Primary energy is consumed through various types of secondary energy (e.g., electricity, heat, gas, and liquids), and electricity has the largest share of all types of secondary energy (Figure 4.1.12). In the NGFS Scenarios (Phase 2), electricity generation is divided into fossil fuels, renewable energy and nuclear power. Fossil fuels are further categorized into those with or without CCS, while renewable energy is further categorized by technology type, such as biomass, solar and wind power.

Scenario characteristics common across the IAMs

In scenarios that assume the introduction of more ambitious emission reduction policies, overall volume of electricity generation in 2050 tends to be higher and the shares of renewable energy and nuclear power tend to be larger (Figure 4.1.9).

Net Zero 2050 and Divergent Net Zero (1.5ºC): Electricity generation volume in 2050 will be the largest of all scenarios, and the volumes and shares of solar[6] and wind power generation will also be the largest. Although there will be some volumes of biomass electricity generation and nuclear power generation, the shares of these two types of generation in overall electricity generation will be small. Fossil fuel-based electricity generation without CCS, which involves CO_2 emissions, will fall to almost zero (Figure 4.1.9(a)(b)).

Below 2ºC and Delayed Transition (1.7ºC~1.8ºC): The overall trend in 2050 will be similar to the trends under the above two scenarios, but electricity generation volume will be somewhat smaller (Figure 4.1.9(c)(d)).

NDCs and Current Policies (2.5ºC~3ºC+): Overall electricity generation volume in 2050 will be the smallest of all scenarios. The share of renewable energy, such as solar power generation and wind power generation, will be small. On the other hand, there will be some residual fossil fuel-based electricity generation without CCS in 2050 (Figure 4.1.9(e)(f)).

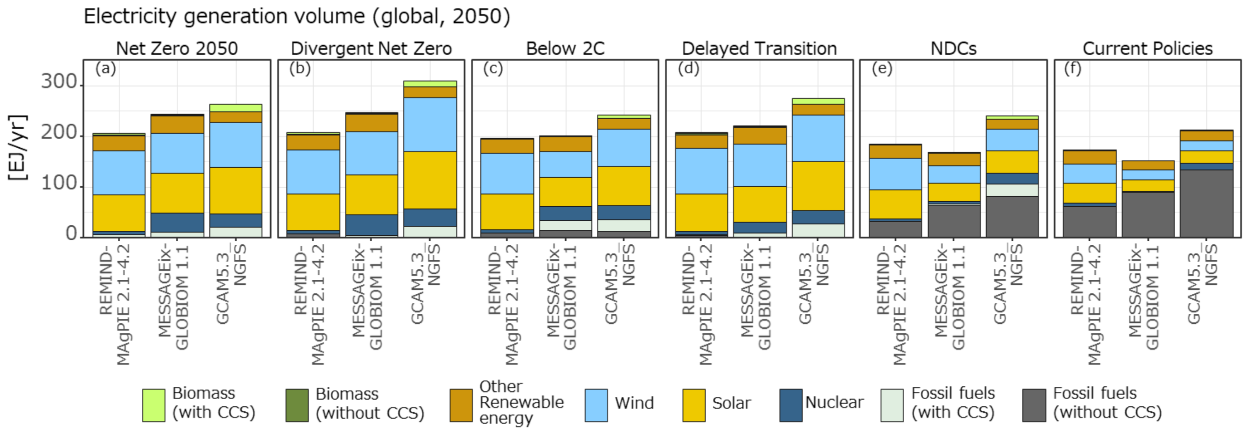


Figure 4.1.9 Breakdown of electricity generation volume in 2050 (global)

<u>Differences between the IAMs</u>

In the Net Zero 2050 scenario, which assumes the introduction of the most ambitious emission reduction policy, there are characteristics specific to the respective IAMs with regard to total electricity generation volume, volumes of biomass and nuclear power generation, and CCS capacity deployed.

REMIND-MAgPIE 2.1-4.2: Total electricity generation will be the smallest of the three IAMs (Figure 4.1.9(a)). Volumes of biomass-based electricity generation (Figure 4.1.9(a) and Figure 4.1.10(a)(b)(i)(j)●), nuclear power generation (Figure 4.1.9(a) and Figure 4.1.10(f)(n)●), and fossil fuel-based electricity generation with CCS (Figure 4.1.9(a) and Figure 4.1.10(f)(n)●) will remain constant and be almost zero in 2050.

MESSAGEix-GLOBIOM 1.1: Total electricity generation will be at a medium level (Figure 4.1.9(a)). Volume of nuclear power generation (Figure 4.1.9(a) and Figure 4.1.10(f)(n)▲) will increase between 2030 and 2050. On the other hand, volumes of biomass power generation (Figure 4.1.9(a) and Figure 4.1.10(a)(b)(i)(j)▲) and fossil fuel-based electricity generation with CCS (Figure 4.1.9(a) and Figure 4.1.10(f)(n)▲) will remain constant and be

[6] "Solar" includes both photovoltaic electricity generation (PV) and concentrated solar power (CSP). In the NGFS Scenarios (Phase 2), separate figures were reported for each of these two types of solar power in the case of REMIND-MAgPIE 2.1-4.2 and GCAM 5.3, but only the total sums for the two types were reported in the case of MESSAGEix-GLOBIOM 1.1. Therefore, in this report, the total sums for the two types are used.

almost zero in 2050.

GCAM 5.3: Total electricity generation will be the largest (Figure 4.1.9(a)). Volume of nuclear power generation (Figure 4.1.9(a)■ and Figure 4.1.10(f)(n)▲) will increase between 2030 and 2050. Volume of biomass-based electricity generation with CCS (BECCS; Figure 4.1.9(a)■ and Figure 4.1.10(a)(i)■) and fossil fuel-based electricity generation with CCS (Figure 4.1.9(a)□ and Figure 4.1.10(f)(n)■) will increase to a certain level by 2050. In 2050, CO_2 emissions from the energy supply sector (electricity) will be negative (Figure 4.1.3) because of biomass-based electricity generation with CCS.

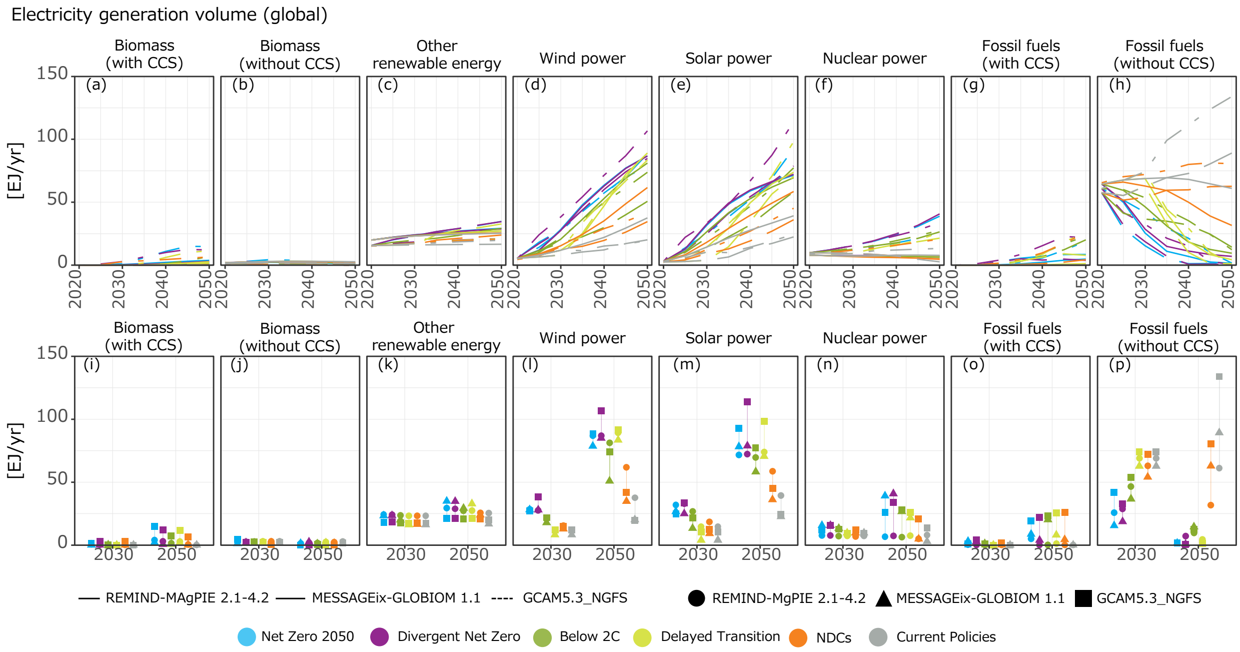


Figure 4.1.10 Changes in electricity generation volume (upper row) and electricity generation volumes in 2030 and 2050 (lower row) (global)

4.1.7 Capital Cost

Capital cost is a determinant of the extent to which a certain technology may be deployed. The NGFS Scenarios (Phase 2) reported on capital cost related to secondary energy (electricity, gas, liquids, and hydrogen). As capital cost (cost per kilowatt excluding fuel cost) differs little across the scenarios within the IAMs, Figure 4.1.11 shows the assumptions of capital cost by power sources in the Net Zero 2050 scenario.

Capital cost of renewable energy (Figure 4.1.11(f)(g)) and fossil fuel-based electricity generation with CCS (Figure 4.1.11(b)(d)) will trend downward towards 2050. Capital cost of coal-based electricity generation with CCS (Figure 4.1.11(b)) and nuclear power generation (Figure 4.1.11(e)) will be higher than the cost of other energy sources.

Differences between the IAMs

According to the Technical Documentation, capital cost is endogenously calculated in a way that reflects a cost decline due to technological development under REMIND-MAgPIE 2.1-4.2 and GCAM 5.3 (NGFS, 2021a). On the other hand, under MESSAGEix-GLOBIOM 1.1, capital cost is an exogenous variable that is given as an input (however, consistency between the capital cost given as an input and the calculation result under the IAMs is checked on an ex-post basis).

REMIND-MAgPIE 2.1-4.2: Compared with GCAM, capital cost of solar power generation (Figure 4.1.11(f)) and offshore wind power (Figure 4.1.11(g)) will be low. Capital cost of coal-based thermal power generation (without CCS) (Figure 4.1.11(a)) will also be somewhat lower than under GCAM.

MESSAGEix-GLOBIOM 1.1: (There is no data reported on capital cost)

GCAM 5.3: Compared with REMIND-MAgPIE 2.1-4.2, capital cost of thermal power generation with CCS (Figure 4.1.11(b)(d)) and nuclear power generation (Figure 4.1.11(e)) will be somewhat low but will remain higher than the cost of other technologies.

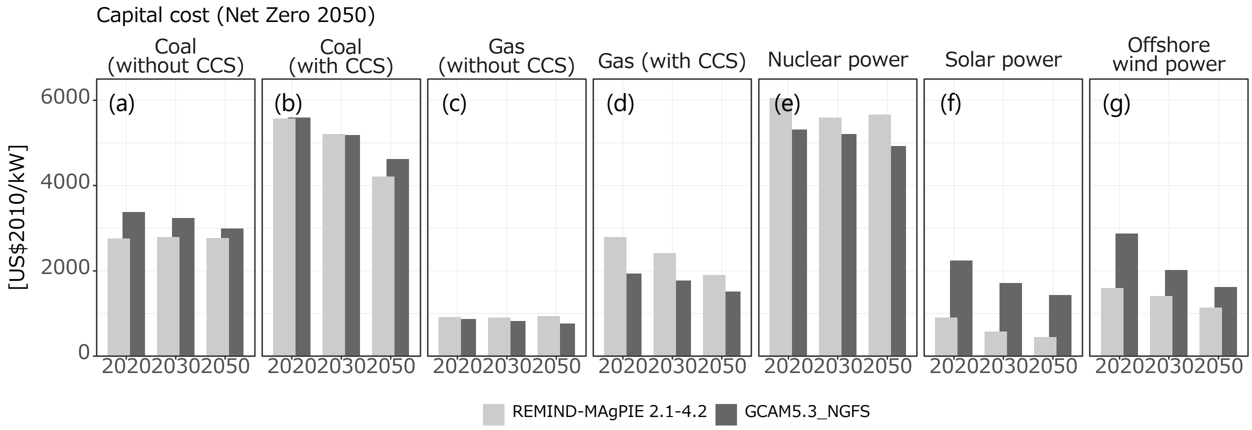


Figure 4.1.11 Assumed capital cost by electricity source (2020, 2030 and 2050) (global)

4.1.8 Final Energy

Final energy is a determinant of the scale and structure of the whole energy system within each IAM. The NGFS Scenarios (Phase 2) reported on final energy with respect to each of energy carriers and energy demand sectors. Here, final energy by energy carriers will be examined.

Scenario characteristics common across the IAMs

Electricity demand will increase under all scenarios (Figure 4.1.13(a)), but the margin of increase in electricity demand in the period through 2050 will vary widely across the scenarios and IAMs (Figure 4.1.13(h)).

Net Zero 2050, Divergent Net Zero, Below 2ºC, and Delayed Transition (1.5ºC~1.8ºC): Across these scenarios, which assume the introduction of emission reduction policies intended to keep the temperature rise below 2ºC or lesser, there is little divergence in terms of overall final energy consumption in 2050 and the breakdown by energy carriers (Figure 4.1.12(a)-(d)). The share of electricity in final energy consumption will be large, while the share of fossil fuels tends to be small (Figure 4.1.12(a-d)).

NDCs and Current Policies (2.5ºC~3ºC+): Final energy consumption in 2050 will be somewhat larger than in the above four scenarios, while the share of fossil fuels tends to be large. In 2050, there will be some residual consumption of coal under all of the IAMs (Figure 12(e)(f)).

Differences between the IAMs

In the Net Zero 2050 scenario, which assumes the introduction of the most ambitious emission reduction policy, there are some characteristics specific to the respective IAMs with regard to the volume of final energy consumption and fossil fuel consumption in 2050.

REMIND-MAgPIE 2.1-4.2: The volume of final energy consumption in 2050 under this model will be the smallest of the three IAMs, as in the case of primary energy consumption. As for fossil fuels, natural gas consumption will be the smallest (Figure 4.1.12(a)■ and Figure 4.1.13(l)●), while liquids (mainly oil) consumption will be large (Figure 4.1.12(a)■ and Figure 4.1.13(m)●). Coal consumption will be almost zero (Figure 4.1.12(a)■ and Figure 4.1.13(n)●).

MESSAGEix-GLOBIOM 1.1: Regarding fossil fuels, natural gas consumption in 2050 will be the largest of the three IAMs (Figure 4.1.12(a)■ and Figure 4.1.13(l)▲). On the other hand, liquids (mainly oil) consumption will be the smallest (Figure 4.1.12(a)■ and Figure 4.1.13(m)▲). Coal consumption will be almost zero (Figure 4.1.12(a)■ and Figure 4.1.13(n)▲).

GCAM 5.3: Compared with the other two IAMs, the share of electricity in 2050 will be somewhat larger (Figure 4.1.12(a)■ and Figure 4.1.13(h)■). As for fossil fuels, natural gas consumption (Figure 4.1.12(a) ■ and Figure 4.1.13(l)■) and liquids consumption (Figure 4.1.12(a)■ and Figure 4.1.13(m)■) will be at a medium level. On the other hand, in 2050, there will be some residual coal consumption (Figure 4.1.12(a)■ and Figure 4.1.13(n)■).

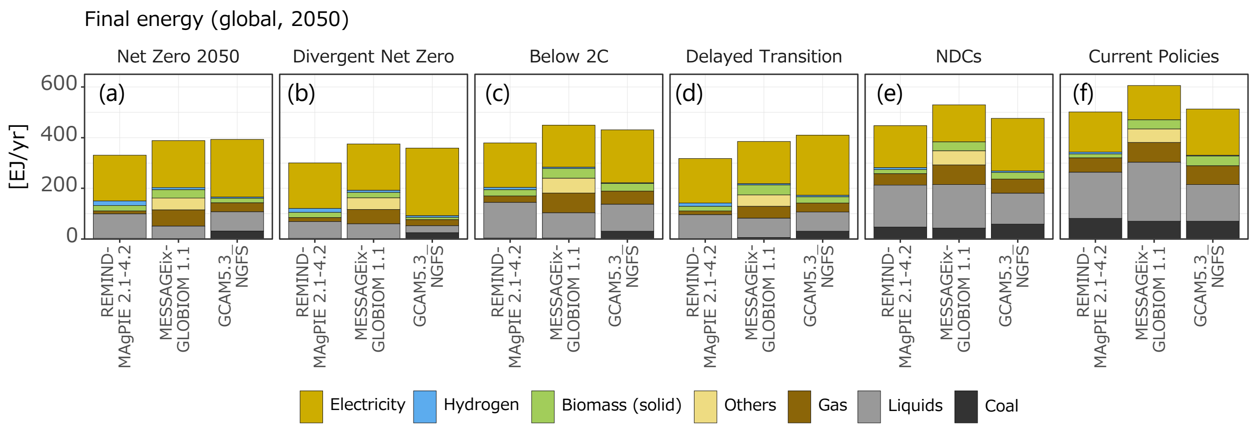


Figure 4.1.12 Breakdown of final energy by energy carriers in 2050 (global)

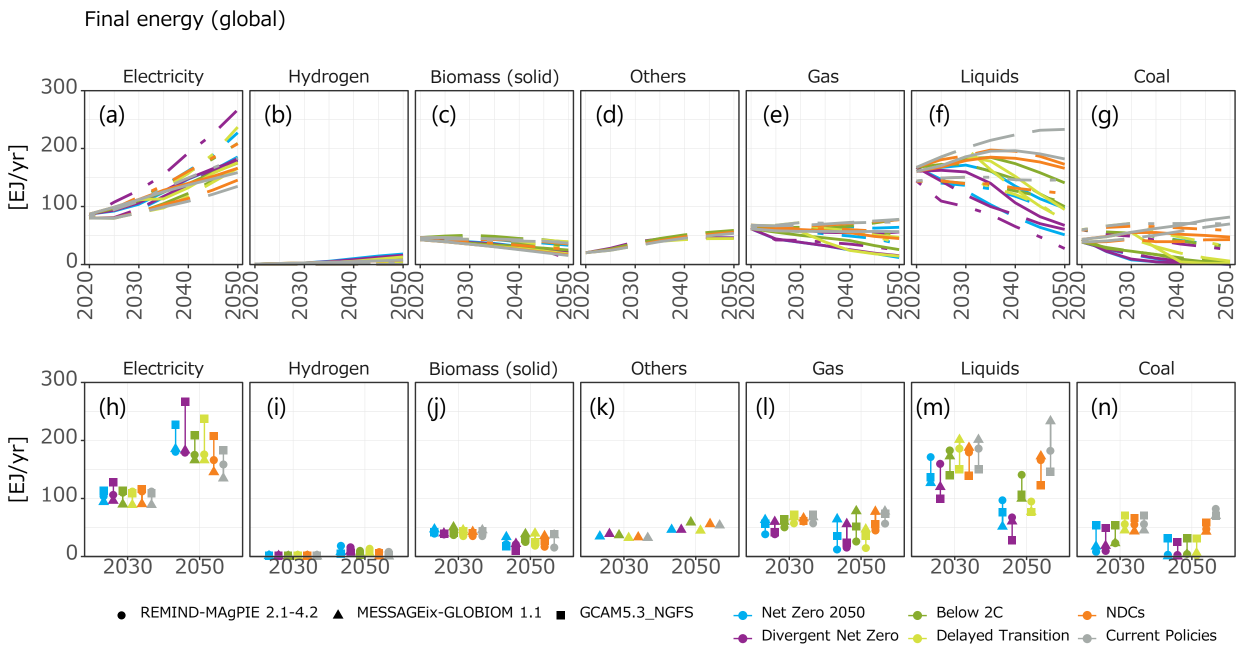


Figure 4.1.13 Pathways of final energy demand (upper row) and demand volumes in 2030 and 2050 (lower row)

4.1.9 Energy Prices

The NGFS Scenarios (Phase 2) reported on energy prices with respect to primary, secondary and final energy.

According to the Technical Documentation regarding the NGFS Scenarios (Phase 2), long-term primary energy prices are calculated within each IAM based on demand changes, resource depletion, and development of exploitation and exploitation technologies, but the effects of carbon pricing are excluded from the calculation.

Scenario characteristics common across the IAMs

Primary energy (fossil fuels) prices will vary widely across the scenarios and the IAMs. Coal price will decline under a slight majority of scenarios. Gas and oil prices will increase towards 2030 and 2050 in most scenarios. Secondary energy (electricity) prices will tend to rise between around 2030 and 2040 and fall back to the 2020 level in 2050 (Figure 4.1.14).

Net Zero 2050 and Divergent Net Zero (1.5ºC) and Below 2ºC (1.7ºC): The more ambitious the policy is, the higher gas prices are (Figure 4.1.14(f)). On the other hand, there is not consistency in the price trends of coal and oil across the IAMs, with uptrends observed in some cases and downtrends in others. Electricity prices will temporarily rise in 2030 (Figure 4.1.14(d)(h)●●●).

Delayed Transition (1.8ºC): There is no consistency in the price trends of gas, coal and oil across the IAMs, with uptrends observed in some cases and downtrends in others. In addition, extreme price changes will occur (Figure 4.1.14(e)(f)(g)●). Electricity prices will temporarily rise between 2035 and 2040 (Figure 4.1.14(d)(h)●).

NDCs (2.5ºC) and Current Policies (to 3ºC+): Gas, coal and oil prices will rise somewhat or remain constant, depending on the IAM (Figure 4.1.14(e)(f)(g)●●). Compared with the above four scenarios, which assume the introduction of emission reduction policies, the range of change in prices will be small. Electricity prices, too, will not change much (Figure 4.1.14(d)(h)●●).

Differences between the IAMs

Regarding the range of change in fossil fuel prices, there are trends specific to the respective IAMs. Temporary price rises and falls are observed under the IAMs in some cases.

REMIND-MAgPIE 2.1-4.2: The range of change in fossil fuel prices will be at a medium level. However, in the Net Zero 2050 and Divergent Net Zero scenarios, a temporary price rise will occur in 2040 (Figure 4.1.14(b)●●). Oil prices in 2050 will be higher than in 2020 in all scenarios (Figure 4.1.14(c)●). Electricity prices will rise sharply, peaking in 2030 in the Net Zero 2050 and Divergent Net Zero scenarios and in 2040 in the Delayed Transition scenario (Figure 4.1.14(d)●●●).

MESSAGEix-GLOBIOM 1.1: The range of change in fossil fuel prices will be the largest of the three IAMs. In the Net Zero 2050 scenario, gas prices in 2050 will be 200% higher than in 2020 (Figure 4.1.14(f)▲). On the other hand, oil prices will fall by 75% (Figure 4.1.14(g)▲). In the Delayed Transition scenario, oil and coal prices will temporarily rise, in 2030 in the case of oil (Figure 4.1.14(c)(g)▲) and in 2040 in the case of coal (Figure 4.1.14(a)(e) ▲). No data on electricity prices was reported.

GCAM 5.3: The range of change in fossil fuel prices will be the smallest of the three IAMs. Coal prices will fall by 2050 (Figure 4.1.14(e)■), while gas prices will trend upward (Figure 4.1.14(f)■), but the range of change is small in both cases. Oil prices will rise in the Net Zero 2050 scenario (Figure 4.1.14(g)■) but fall in the Delayed Transition scenario (Figure 4.1.14(g) ■). The range of change in electricity prices will be small (Figure 4.1.14(h)■).

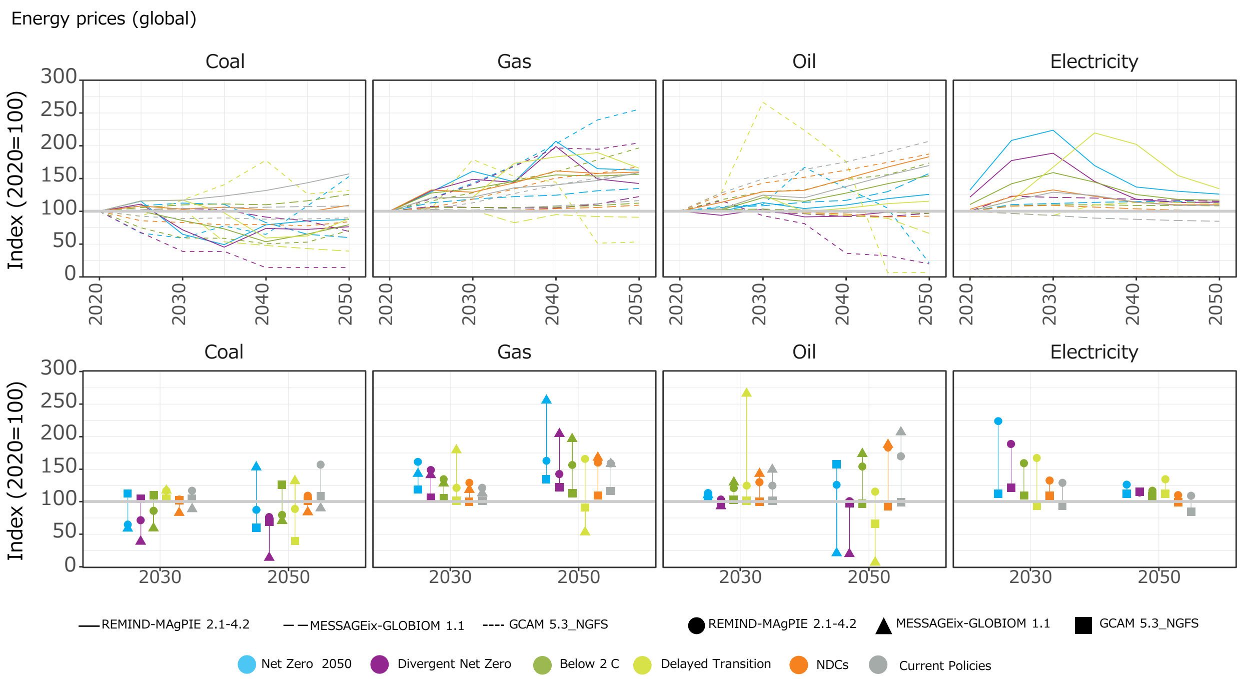


Figure 4.1.14 Pathways of energy prices (upper row) and price levels in 2030 and 2050 (lower row) (global)

4.1.10 Energy Investment (Cumulative Total until 2050)

Energy investment is a determinant of the future energy system structure. The NGFS Scenarios (Phase 2) reported on investment value with regard to the extraction and refining of fossil fuels and electricity generation, transmission and distribution. Here, we look at cumulative investment until 2050 regarding fossil fuels (including investment in extraction, refining, electricity generation, and CCS) electricity generation (solar, wind and nuclear power), electricity transmission and distribution, and electricity storage.

Scenario characteristics common across the IAMs

In the four scenarios that assume the introduction of ambitious emission reduction policies (Net Zero 2050, Divergent Net Zero, Below 2ºC, and Delayed Transition), the energy investment value will be larger than in the other two scenarios (NDCs and Current Policies) (Figure 4.1.15). The value of investment in electricity transmission and distribution will be the largest in all scenarios.

Net Zero 2050, Divergent Net Zero (1.5ºC), Below 2ºC (1.7ºC), and Delayed Transition (1.8ºC): Across these scenarios, the value of cumulative investment until 2050 and the breakdown by investment item will be mostly similar. While the share of electricity transmission and distribution■ will be the largest, the shares of solar power generation■ and wind power generation■ will also be large (Figure 4.1.15).

NDCs (2.5ºC) and Current Policies (~3ºC+): The value of cumulative investment until 2050 and the value of investment by item will be smaller than in the above four scenarios. The shares of solar power generation■ and wind power generation■ will be small, while investment in fossil fuels■ will continue at a certain level (Figure 4.1.15).

Differences between the IAMs

There are characteristics specific to the respective IAMs with regard to the value of cumulative investment until 2050 and the shares of fossil fuels, renewable energy, and nuclear power in investment.

REMIND-MAgPIE 2.1-4.2: The value of cumulative investment until 2050 is the largest of the three IAMs (Figure 4.1.15). The value of investment in wind power generation and in energy storage will be larger than under the other IAMs. On the other hand, the value of investment in nuclear power generation will be small. (Figure 4.1.16●).

MESSAGEix-GLOBIOM 1.1: The value of cumulative investment until 2050 will be at a medium level (Figure 4.1.15). While the value of investment in nuclear power generation will be large, the value of investment in electricity transmission and distribution will be small (Figure 4.1.16▲).

GCAM 5.3 (■): The value of cumulative investment until 2050 will be the smallest of the three IAMs (Figure 4.1.15). The value of investment in fossil fuels will be large across all scenarios. The value of investment in wind power generation, electricity transmission and distribution, and energy storage will be small.

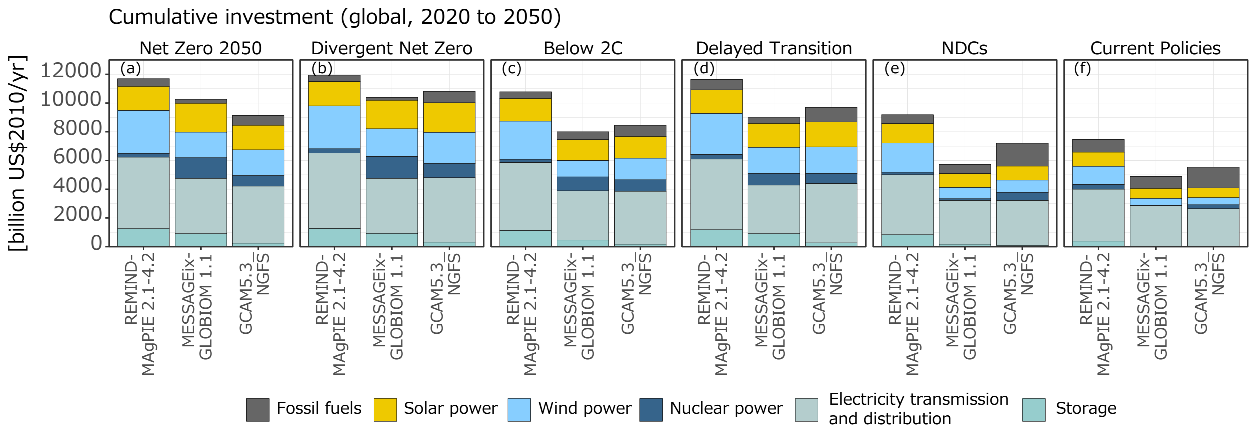


Figure 4.1.15 Cumulative energy-related investment (2020-2050, total value)

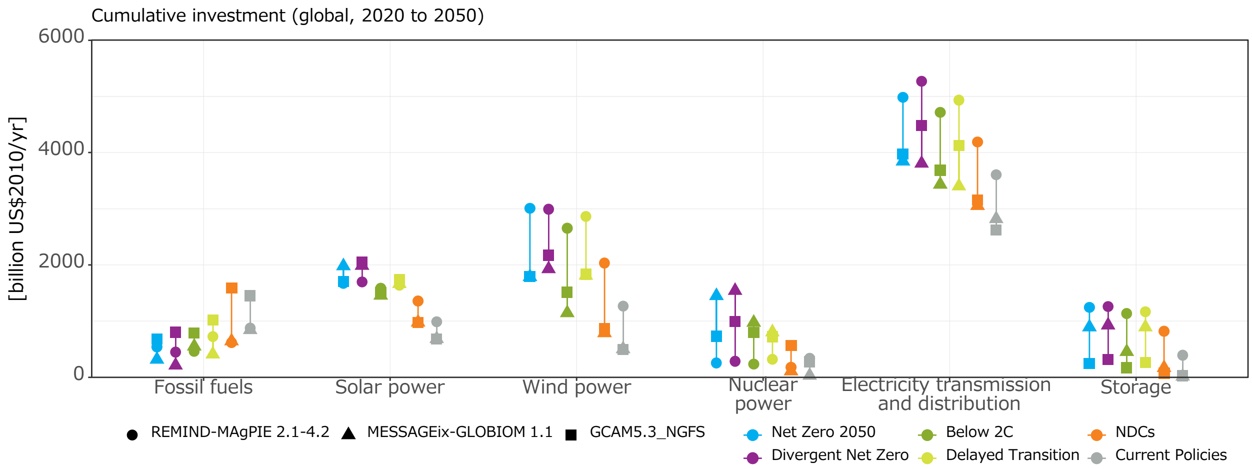


Figure 4.1.16 Cumulative energy-related investment (2020-2050, by sector)

4.1.11 Summary: Characteristics of the NGFS Scenarios at the Global Level

The previous subsections explained the characteristics of the scenarios and IAMs that depend on variables regarding CO_2 emissions and removals, the detailed impact of the energy supply-demand balance on CO_2 emissions, and energy prices and energy-related investment, which affect the energy supply structure. In light of those characteristics, this subsection examines the characteristics of the NGFS scenarios at the global level.

Changes in the energy system

As the energy sector accounts for a large portion of CO_2 emissions, how the energy system changes is an important factor for achieving the required level of emissions reduction set in each scenario in the NGFS Scenarios (Phase 2).

In scenarios that assume the introduction of ambitious emission reduction policies (e.g., Net Zero 2050), the share of fossil fuels in primary energy consumption in 2050 is small, while the share of renewable energy is large (Figure 4.1.7). Primary energy includes energy consumed after conversion into secondary energy, such as electricity, and the volume of renewable energy used for electricity generation tends to increase significantly in those ambitious scenarios (e.g., Net Zero 2050) (Figures 4.1.9 and 4.1.10).

Figure 4.1.17 shows changes in the relationship between the share of electricity in final energy consumption (electrification rate) and the share of non-fossil fuel energy (total sum of renewable energy and nuclear power) in electricity generation (the non-fossil fuel share in the electricity source mix) between 2020 to 2050. In 2020, the electrification rate was only around 20% and the share of non-fossil fuel energy was slightly below 40%. In 2050, in scenarios that assumes the introduction of ambitious emission reduction policies (e.g., Net Zero 2050), the electrification rate will rise to 50-70%, and the non-fossil fuel share will climb to slightly above 90%. However, in scenarios that do not assume the introduction of emission reduction policies (e.g., Current Policies), the margin of change in those rates will remain small.

The above trends indicate that the reduction of energy-derived CO_2 emissions will proceed in terms of both electrification of final energy consumption and decarbonization of electricity supply.

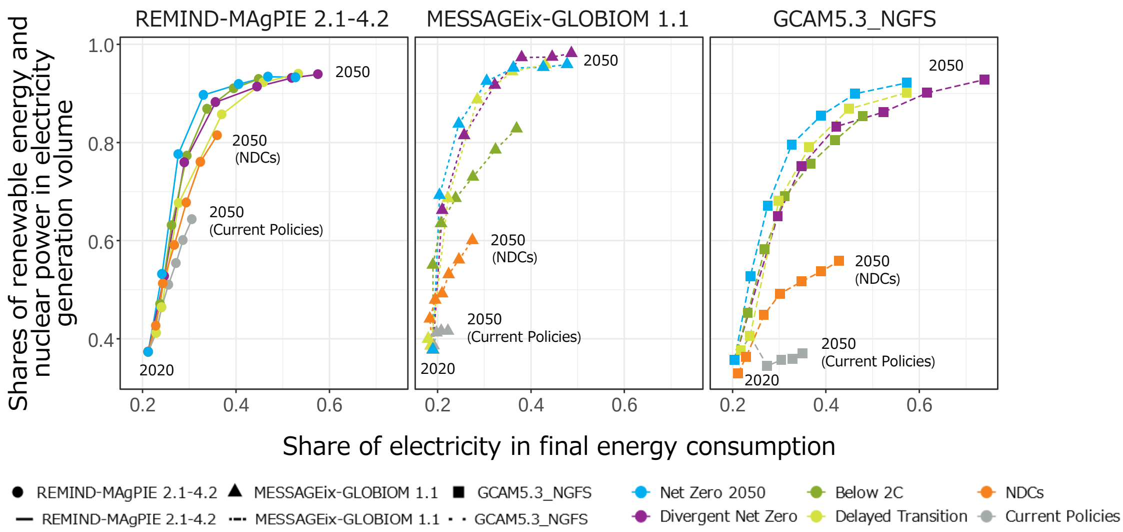


Figure 4.1.17 Relationship between the share of electricity in final energy consumption (electrification rate) and share of non-fossil electricity sources (renewable energy electricity generation and nuclear power generation) in

electricity generation (the non-fossil fuel share in the electricity source mix); changes between 2020 and 2050 (figures for every five years) (global)

Residual emissions and achievement of net zero emissions

Residual emissions, i.e., emissions that remain after reductions achieved through the energy system alone, will have to be addressed by means of CO_2 removal technology. In the Below 2ºC and Net Zero 2050 scenarios, there is a difference in the volume of negative emissions due to CO_2 removals by sector in 2050 (Figures 4.1.3 and 4.1.4). By sector, there will be residual emissions in the transport and industry sectors, where decarbonization is more difficult. In the Net Zero 2050 scenario, the residual emissions will be offset by negative emissions through CO_2 removal technology (Figure 4.1.5).

As CO_2 removal technology is costly, carbon prices will rise significantly towards 2050 in scenarios that assume extensive deployment of the technology (Figure 4.1.18). Within each IAM, carbon prices will impose additional cost for the entire economy in line with CO_2 emissions. In other words, ambitious scenarios will inevitably rely on expensive emission reduction technology, and the effects will appear in the form of a rise in carbon prices reflecting the stringency of climate policy under the models.

However, carbon prices obtained in the NGFS scenarios depend on the formularization of the entire energy flow, including the method of optimization calculation and various price conditions, that is distinctively set within each IAM. There are various social obstacles in deployment of CO_2 removal technology other than high cost although they are not discussed in detail here. Therefore, in the real world, even if carbon prices are set at the same level as in the IAMs, CO_2 removal technology may not necessarily be deployed, and while its deployment may be promoted through other policy measures. Given that in the real world, there are policy measures other than carbon pricing, it may be said that carbon prices under the IAMs are a relative indicator of differences in the stringency of climate policy across the scenarios.

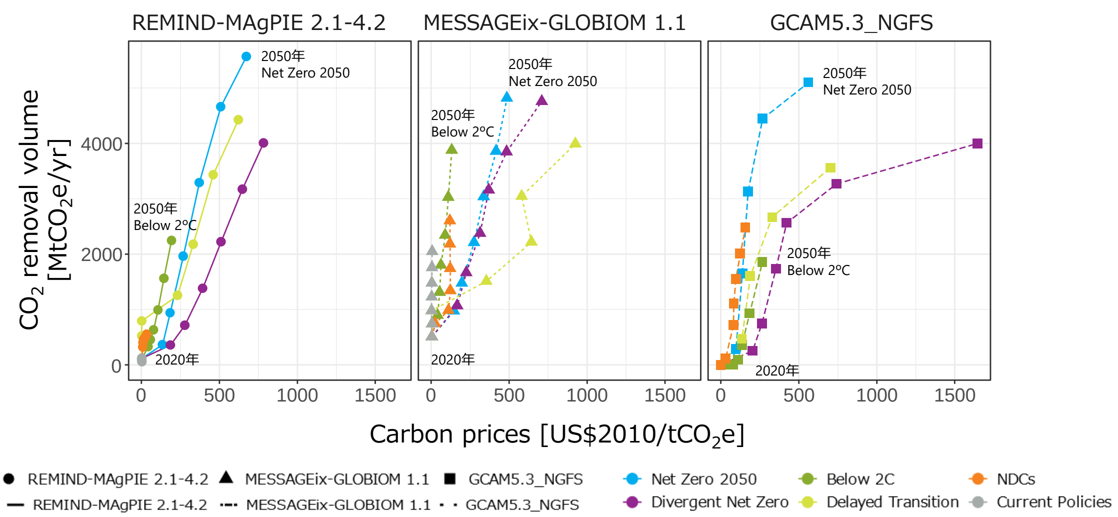


Figure 4.1.18 Relationship between carbon prices and CO_2 removals; changes between 2020 and 2050 (figures for every five years) (global)

Electricity source mix (differences in volume of non-fossil electricity generation)

In ambitious scenarios (e.g., Net Zero 2050), the shares of solar and wind power in the renewable energy/nuclear power category will be large in 2050 (Figure 4.1.9). In terms of the value of cumulative investment from 2020 to 2050, the shares of solar and wind power in the electricity generation sector will be large (Figure 4.1.16). On the other hand, the share of nuclear power, which, together with renewable energy, is classified as a non-fossil electricity source, will be smaller than the shares of solar and wind power although it varies across the IAMs (Figure 4.1.9).

These differences are presumably affected by the respective capital cost of specific technologies that are set within the IAMs. For the period from 2020 to 2050, the capital cost of solar and wind power[7] is set at a low level, whereas the cost of nuclear power is generally high, resulting in a significant difference between the costs of the renewable energy and nuclear power (Figure 4.1.11).

The difference in the volume of power generation between technologies with a small difference in capital cost cannot be explained by capital cost alone. For example, in the case of solar and wind power under REMIND-MAgPIE 2.1-4.2 and GCAM 5.3 (Figure 4.1.11), capital cost is slightly lower under REMIND-MAgPIE 2.1-4.2 but electricity generation volume in 2050 is larger under GCAM 5.3 for both solar and wind power (Figure 4.1.10). The results presumably reflect the combined effects of other assumptions set within each IAM, including maximum capacity that may be deployed, capacity utilization, and additional cost necessary for connecting renewable energy with electricity systems, including transmission and distribution lines and storage batteries (integration cost).

As explained above, although the IAMs produce consistent outcomes under their respective formularizations and assumptions, it is not necessarily easy to explain the calculation results. Integrated Assessment Modeling Consortium—a representative research community for developing scenarios using IAMs—is also aware of this problem and is continuing activity to better understand the behavior of IAMs.

[7] The NGFS Scenarios (Phase 2) reported on the cost of offshore wind power, but the cost of onshore wind power is even lower than that.

4.2 Overview of the NGFS Scenarios (Phase 2): Japan Scenarios

The previous section provided an overview of the outcome of the key variables of the NGFS scenarios for the world. This section provides an overview of the outcome of the key variables of the scenarios for Japan analyzed from the same viewpoint.

4.2.1 CO_2 Emissions

Scenario characteristics common across the IAMs

While the relative scales of emissions between the six scenarios are the same for Japan and the world, the scenarios for Japan show the following distinctive characteristics.

Net Zero 2050 and Divergent Net Zero: As these two scenarios assume early introduction of ambitious emission reduction policies ("policy ambition" is "1.5°C" and "policy reaction" is "immediate"), the pace of reduction of CO_2 emissions is fast enough to lower net emissions in 2050 to almost zero or to a negative figure (Figure 4.2.1●●).

Below 2ºC: As a result of early introduction of an intermediate-level emission reduction policy ("policy ambition is "1.7 ºC" and "policy reaction" is "immediate"), emission reduction will make progress towards 2050 (Figure 4.2.1●).

Delayed Transition: While this scenario assumes introduction of an intermediate-level emission reduction policy after 2030 onwards ("policy ambition" is "1.8°C" and "policy reaction" is "delayed"), emission reduction starts before 2030 depending on IAMs, resulting in a smaller emission volume in 2050 —almost zero or a negative emission— compared with the Below 2ºC scenario (Figure 4.2.1●).

NDCS and Current Policies: Emissions will decrease in Japan towards 2050 despite of weak emissions reduction policy, despite emissions will increase in the same periods in the world (Figure 4.2.1●●).

Characteristics of the IAMs:

The relative scales of emissions between the scenarios for Japan and the world are mostly the same. However, the disparities among IAMs in terms of the absolute emission volume are slightly larger for Japan than compared with the world (Figure 4.2.1(b)).

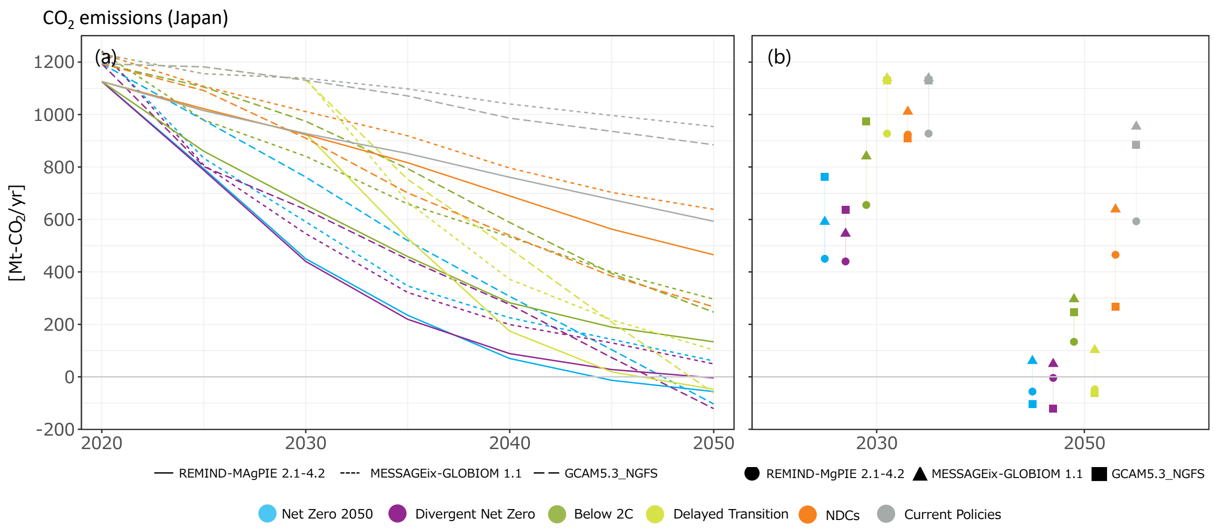


Figure 4.2.1 Pathways of Japanese CO_2 emissions (left) and volumes of emissions in 2030 and 2050 (right)

4.2.2 Carbon Prices

Scenario characteristics common across the IAMs

In line with the worldwide trend, in Japan, carbon prices will rise higher towards 2050 in scenarios that assume the introduction of more ambitious emission reduction policies. Compared with the worldwide trend in carbon prices, the margin of increase in carbon prices in Japan is larger (Figure 4.2.2).

Net Zero 2050: As a result of early introduction of an ambitious emission reduction policy (1.5°C) ("policy reaction" is "immediate"), carbon prices will rise towards 2050 (Figure 4.2.2(b)●).

Divergent Net Zero: As a result of early and disorderly introduction of an ambitious emission reduction policy (1.5°C) ("policy reaction" is "immediate but "divergent" across sectors"), carbon prices will rise towards 2050 (Figure 4.2.2 (b)●).

In Divergent Net Zero, as carbon prices for the "transport" and "residential and commercial" sectors have been set at triple the level in other sectors, overall carbon prices are expected to be higher than in Net Zero 2050, which assumes the introduction of an emission reduction policy of the same level of ambition. However, in Japan's case, carbon prices will be lower in "Divergent Net Zero" than in "Net Zero 2050 under the "REMIND-MAgPIE 2.1-4.2" model.[8]

Below 2ºC: As a result of introduction of an intermediate-level emission reduction policy (1.7ºC), the margin of increase in carbon prices in 2030 and 2050 will be smaller compared with Net Zero 2050 (●) (Figure 4.2.2 (b)●).

Delayed Transition: Although the ambitiousness level of the emission reduction policy introduced is medium (1.8ºC), the timing of introduction will be late ("policy reaction" is "delayed"). While the carbon price will be almost zero in 2030, it will be higher than the level in Net Zero 2050 (●) in 2050 (Figure 4.2.2 (b)●).

NDCs and Current Policies: As a result of introduction of an emission reduction policy equivalent to the current one (2.5°C to 3°C+), the carbon price will be zero or near zero in 2030 and 2050 (Figure 4.2.2 (b)●●).

Differences between the IAMs (overall trends)

In Japan as well, the relative carbon price levels between Net Zero 2050 (1.5ºC), Divergent Net Zero (1.5ºC), and Delayed Transition (1.8ºC) are different between the IAMs as shown below (Figure 4.2.2 (b)).

REMIND-MAgPIE 2.1-4.2: Delayed Transition● (1.8ºC) > Net Zero 2050● (1.5ºC) > Divergent Net Zero● (1.5ºC)

MESSAGEix-GLOBIOM 1.1: Delayed Transition (1.8ºC)▲ > Divergent Net Zero▲ (1.5ºC) > Net Zero 2050▲ (1.5ºC)

GCAM 5.3: Divergent Net Zero (1.5ºC)■ >> Delayed Transition (1.8ºC)■ > Net Zero 2050■ (1.5ºC)

[8] In the NGFS Scenarios (Phase 2, Version 2.2), the carbon price (Price|Carbon) in Divergent Net Zero under REMIND-MAgPIE 2.1-4.2 is the same as the price reported for the industrial sector (Price|Carbon|Industry) and the energy supply sector (Price|Carbon|Supply). Normally, the carbon prices in the transport (Price|Carbon|Transport) and the residential and commercial sectors (Price|Carbon|Residential and Commercial), which are set at triple the level in the industry and energy supply sectors, should be reflected in the overall carbon price, but they have not been reflected for some reason.

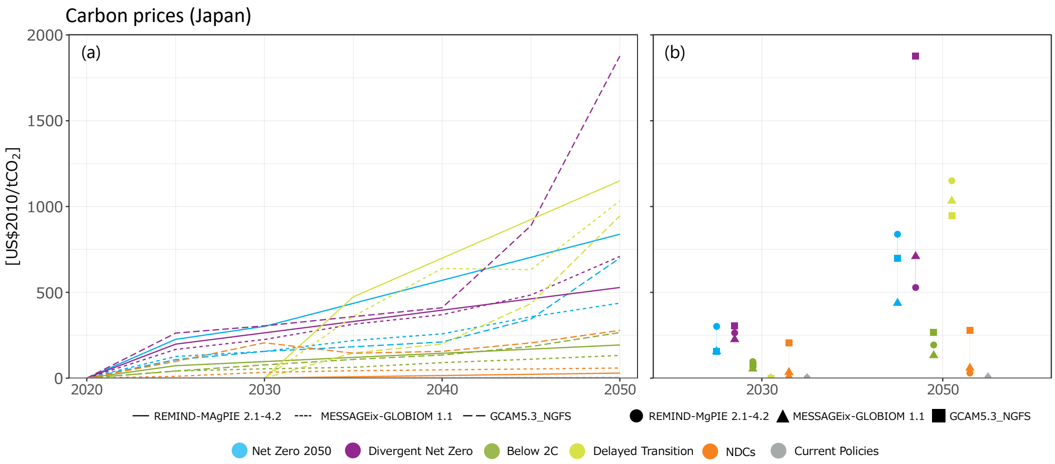


Figure 4.2.2 Pathways of Japanese carbon prices (left) and carbon prices in 2030 and 2050 (right)

4.2.3 CO_2 Emissions by Sector

<u>**Scenario characteristics common across the IAMs**</u>

CO_2 emission volume in 2050 will fall closer to zero in scenarios that assume more ambitious reduction policies. Compared with the worldwide trend, residual emissions in the transport■ and industrial■ sectors will be smaller, while the margin of the negative emission in the energy supply sector (electricity■ and others■) will be larger. In the AFLOU sector■ (land use), emissions will be close to zero in all scenarios, indicating that changes in land use will have little impact (Figure 4.2.3).

Net Zero 2050 and Divergent Net Zero (1.5ºC): In 2050, CO_2 emission volume in the transport sector■ will be the smallest, while emissions from the energy supply sector (electricity■ and others■) will be negative (Figure 4.2.3(a)(b)).

Below 2ºC (1.7ºC): In 2050, CO_2 emission volume in the transport sector■ will be at a medium level, while emission volume in the energy supply sector (electricity■ and others■) will be near zero (Figure 4.2.3(c)).

Delayed Transition (1.8ºC): Unlike the worldwide trend, emission volume will be similar to the levels in Net Zero 2050 and Divergent Net Zero (1.5ºC), with emissions from the energy supply sector (electricity■ and others■) becoming negative (Figure 4.2.3(d)).

NDCS and Current Policies (2.5ºC to 3ºC+): In 2050, there will be residual CO_2 emissions in the industrial sector■, the transport sector■, and the energy supply sector (electricity■ and others■) and in industrial processes■ (Figure 4.2.3 (e)(f)).

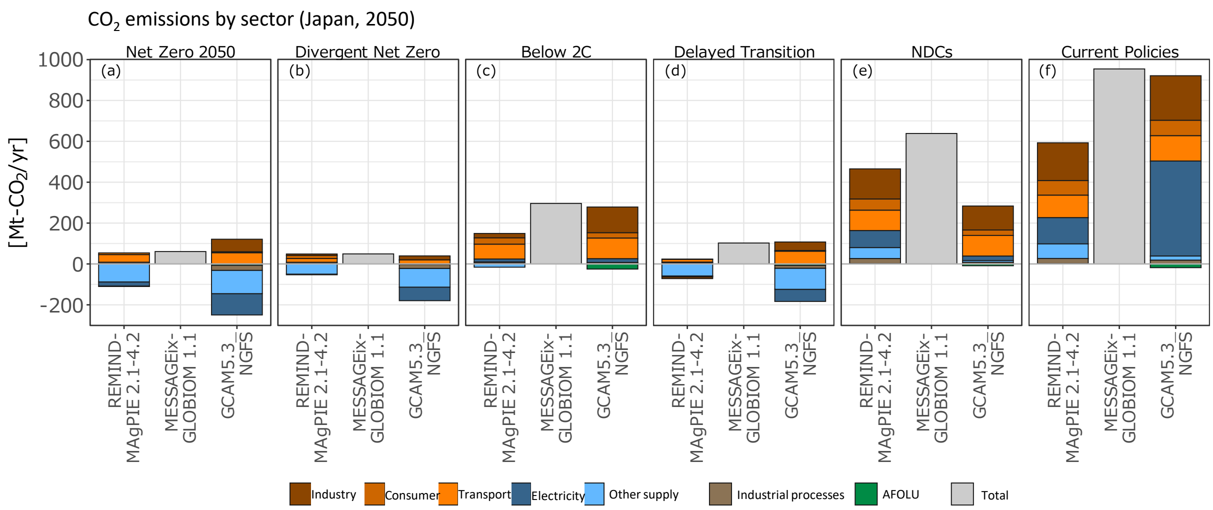


Figure 4.2.3 CO_2 emissions by sector in 2050

Differences between the IAMs

Compared with the worldwide trend, differences between the IAMs in terms of net emission volume are slightly larger (Figure 4.2.3), and there are also differences between the IAMs in terms of emission volume and emission pathway by sector (Figure 4.2.4). Of the three IAMs, MESSAGEix-GLOBIOM 1.1 does not provide a report on the breakdown of CO_2 emissions by sector in Japan.

REMIND-MAgPIE 2.1-4.2: In the industrial sector, emission reduction will make quick progress by 2030, and emission volume will decline to almost zero in 2050 (Figures 4.2.3(a)■ and 4.2.4 (h)●). In the energy supply sector, the margin of negative emission will be large with respect to "other supply" (other than electricity) (Figures 4.2.3(a)■ and 4.2.4(l)●).

MESSAGEix-GLOBIOM 1.1: There is no report on the breakdown of emissions by sector in Japan.

GCAM 5.3: In 2030, emission volumes in both the industrial and electricity sectors will be large. In 2050, there will be residual emissions in the industrial sector (Figures 4.2.3(a)■ and 4.2.4(h)■), while emissions in the electricity sector will be negative (Figures 4.2.3(a)■ and 4.2.4(k)■).

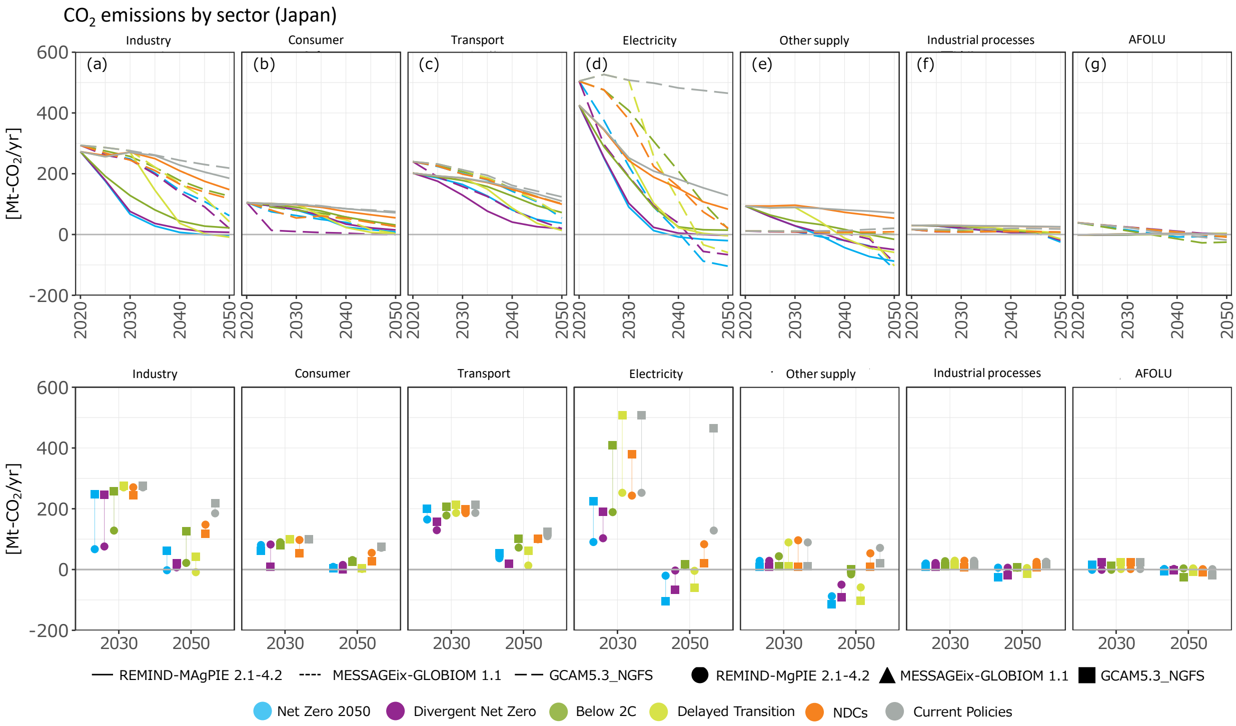


Figure 4.2.4 Pathways of CO_2 emissions by sector (upper row) and volumes of emissions in 2030 and 2050 (lower row)

4.2.4 CO_2 Removals

<u>Scenario characteristics common across the IAMs</u>

In line with the worldwide trend, there will be differences between the scenarios in terms of the volume of CO_2 removals by BECCS. On the other hand, unlike the worldwide trend, the volume of CO_2 removals by afforestation in Japan will be zero.

Net Zero 2050 and Divergent Net Zero (1.5ºC): In line with the worldwide trend, CO_2 removals by BECCS will make progress (Figure 4.2.5 (a)(b)■■■■).

Below 2ºC (1.7ºC): Although CO_2 removals by BECCS will make progress, the removal volume will be smaller than in the above two scenarios (Figure 4.2.5 (c)■■■■).

Delayed Transition (1.8ºC): As a result of rapid emission reduction from 2030 onwards, the volume of CO_2 removals by BECCs in 2050 will be larger than in "Below 2ºC" (Figure 4.2.5 (d)■■■■).

NDCs and Current Policies (2.5ºC to 3ºC+): The volume of CO_2 removals by BECCS will be small (Figure 4.2.5 (e)(f)).

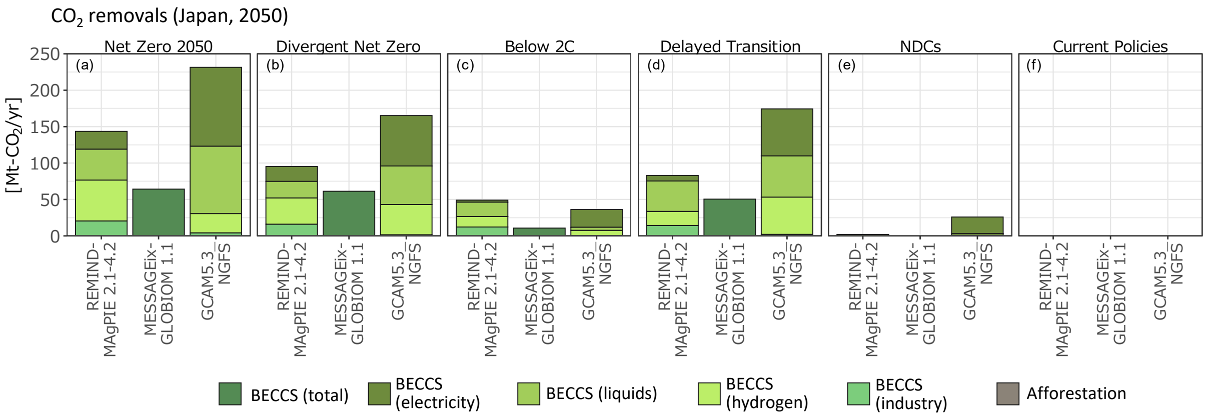


Figure 4.2.5 CO_2 removal capacity introduced in 2050 and the breakdown by type of technology (Under GCAM 5.3, there has been no report on CO_2 removals by afforestation) (Japan)

<u>Differences between the IAMs</u>

While almost all CO_2 removals will be due to BECCS, there are differences between the IAMs in terms of sector-by-sector deployment of BECCS and CO_2 removal volume.

REMIND-MAgPIE 2.1-4.2: The volume of BECCS deployed by 2050 will be relatively small, with deployment expected with respect to liquid fuels (Figures 4.2.5■and 4.2.6(b)(f)) and hydrogen (Figures 4.2.5■ and 4.2.6(c)(g)).

MESSAGEix-GLOBIOM 1.1: Regarding Japan, only the overall volume of BECCS capacity is reported, and the removal volume is the smallest of the three IAMs (Figure 4.2.5■).

GCAM 5.3: The volume of BECCS deployed by 2050 will be relatively large, with introduction expected with respect to all of electricity (Figures 4.2.5■ and 4.2.6(a)(e)), liquid fuels (Figures 4.2.5■ and 4.2.6(b)(f)) and hydrogen (Figures 4.2.5■ and 4.2.6(c)(g)). While there is no report on the volume of removals due to afforestation, the volume of CO_2 removals due to afforestation in Japan is presumed to be close to zero given that the CO_2 removal volume in the AFOLU sector (land use) in the country is almost zero (Figure 4.2.6(d)(h)).

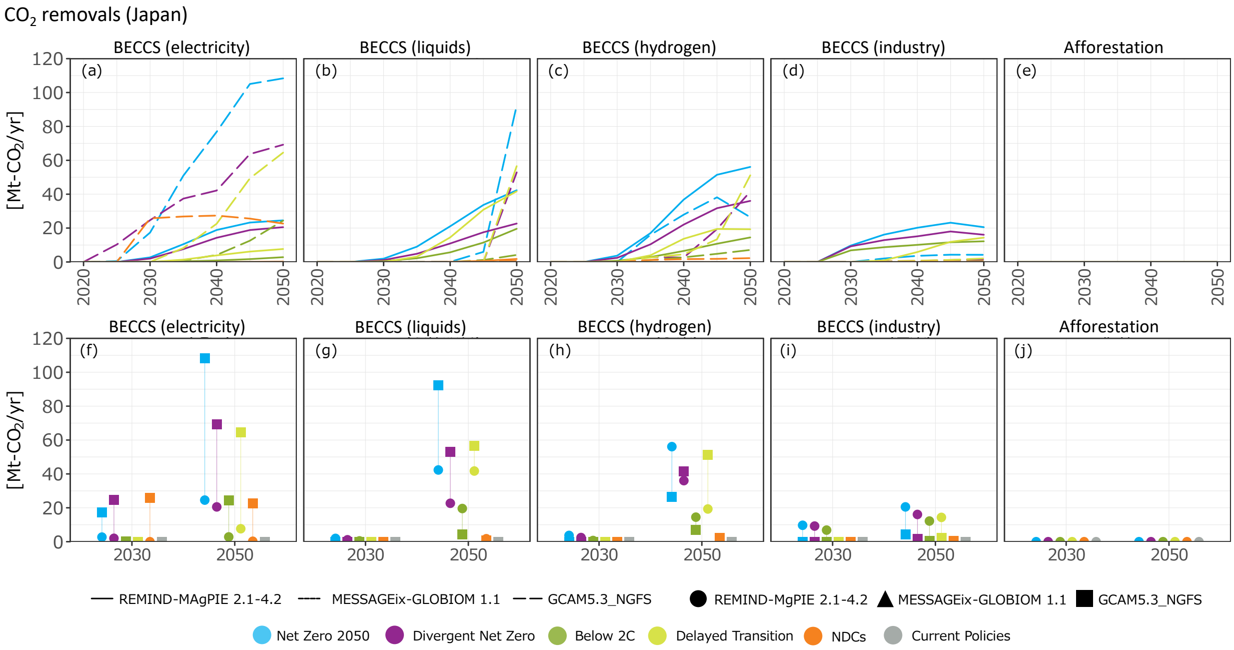


Figure 4.2.6 Pathways of CO_2 removals by sector (upper row) and removal volumes in 2030 and 2050 (lower row)

4.2.5 Primary Energy

__Scenario characteristics common across the IAMs__

In line with the worldwide trend, the overall volume of primary energy in 2050 will be smaller in the four scenarios that assume introduction of an emission reduction policy equivalent or more ambitious to Below 2ºC (Figure 4.2.7 (a)-(d)) than in other scenarios (NDCs and Current Policies, Figure 4.2.7(e)(f)). Compared with the worldwide trend, the volume of renewable energy will rise higher towards 2050 (Figure 4.2.8 (b)(j)) and the share of biomass is larger.

Net Zero 2050 and Divergent Net Zero (1.5ºC): The volume of renewable energy (■□) in 2050 in this scenario will be the largest of all scenarios. Compared with the worldwide trend, the share of biomass is larger. Regarding fossil fuels without CCS, the volumes of coal■ and natural gas■ will be close to zero, but there will be some residue consumption of oil■ in 2050 (Figure 4.2.7 (a)(b)).

Below 2ºC (1.7ºC): The volume of renewable energy (biomass■ in particular) will be slightly smaller compared with Net Zero 2050 and Delayed Transition. The volume of residual consumption of oil (■) in 2050 will be slightly larger than in Net Zero 2050 (Figure 4.2.7 (c)).

Delayed Transition (1.8ºC): The uptrend of renewable energy (■□) and the downtrends of coal (■) and natural gas (■) towards 2050 are similar to the ones observed in Net Zero 2050. On the other hand, the volume of oil (■) in 2050 will be slightly larger than in Net Zero 2050 (Figure 4.2.7 (d)).

NDCs and Current Policies (2.5ºC to 3ºC+): Although the volume of renewable energy (■□) will increase towards 2050 in line with the worldwide trend, the volume of introduced capacity will be smaller than in the above four scenarios. On the other hand, the volume of fossil fuels without CCS (coal■, natural gas■, and oil■) will be large (Figure 4.2.7 (e)(f)).

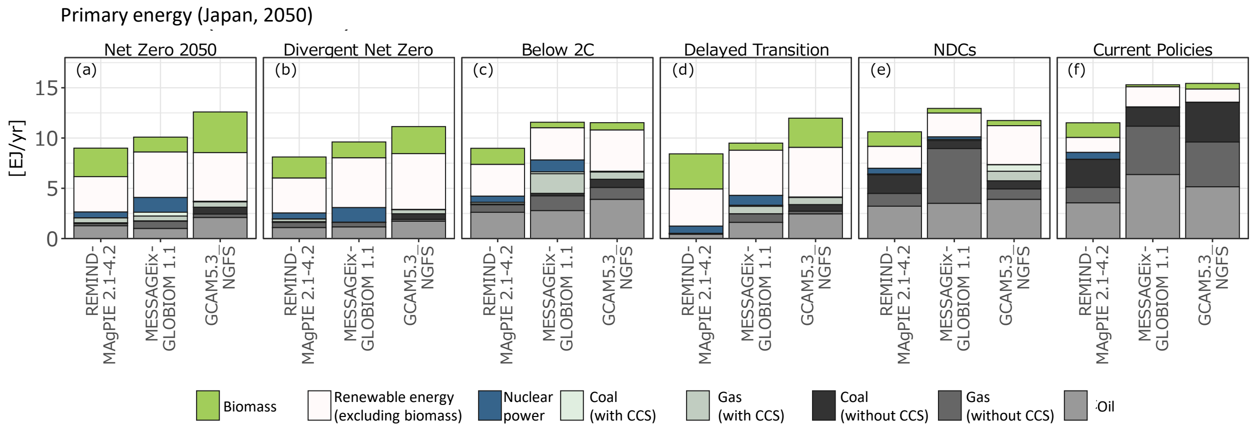


Figure 4.2.7 Primary energy by sector in 2050 (Japan)

<u>Differences between the IAMs</u>

In Net Zero 2050, which assumes introduction of the most ambitious emission reduction policy, volumes of all types of fossil fuels without CCS (coal, gas and oil) will decrease towards 2050 (Figures 4.2.7(a) and 4.2.8 (f)-(h)) in line with the worldwide trend, but the relative scales of volumes between the scenarios differ across the IAMs (Figure 4.2.8(n)-(p)).

REMIND-MAgPIE 2.1-4.2: The volume of primary energy in 2050 will be the smallest of the three IAMs (Figure (4.2.7(a)). Of the fossil fuels without CCS, the volume of coal will rapidly decline by 2030 and fall to almost zero in 2050 (Figures 4.2.7(a)■ and 4.2.8(n)●). The volume of natural gas in both 2030 and 2050 will be the smallest (Figures 4.2.7(a)■ and 4.2.8(o)●). Unlike the worldwide trend, the share of nuclear power is at a medium level (Figures 4.2.7(a) ■ and 4.2.8(k) ●).

It should be noted that the volume of nuclear power will remain almost constant at all points in time and in all scenarios (Figure 4.2.8(k)●).

MESSAGEix-GLOBIOM 1.1: The volume of primary energy in 2050 will be at a medium level (Figure 4.2.7(a)). Of the fossil fuels without CCS, the volume of coal will decline rapidly until 2030 and fall to almost zero in 2050 (Figures 4.2.7(a)■ and 4.2.8(n)▲). The volume of natural gas in both 2030 and 2050 will be the largest (Figures 4.2.7(a)■ and 4.2.8(o)▲). The share of nuclear power is the largest (Figures 4.2.7(a) ■ and 4.2.8(k)▲).

GCAM 5.3: The volume of primary energy in 2050 will be the largest (Figure 4.2.7(a)). The total volumes of fossil fuels without CCS (coal, gas and oil) will be larger than under the other IAMs (Figures 4.2.7(a) ■■■ and 4.2.8 (n)-(p)). The volume of coal will be larger than under the other IAMs. Although the volume of coal will not fall to zero in 2050, the margin of decline towards 2050 will be larger compared with the worldwide trend (Figures 4.2.7(a)■ and 4.2.8 (n)■). The volumes of natural gas (Figures 4.2.7(a)■and 4.2.8(o)■) and nuclear power (Figures 4.2.7(a)■ and 4.2.8(k)■) will be at a medium level.

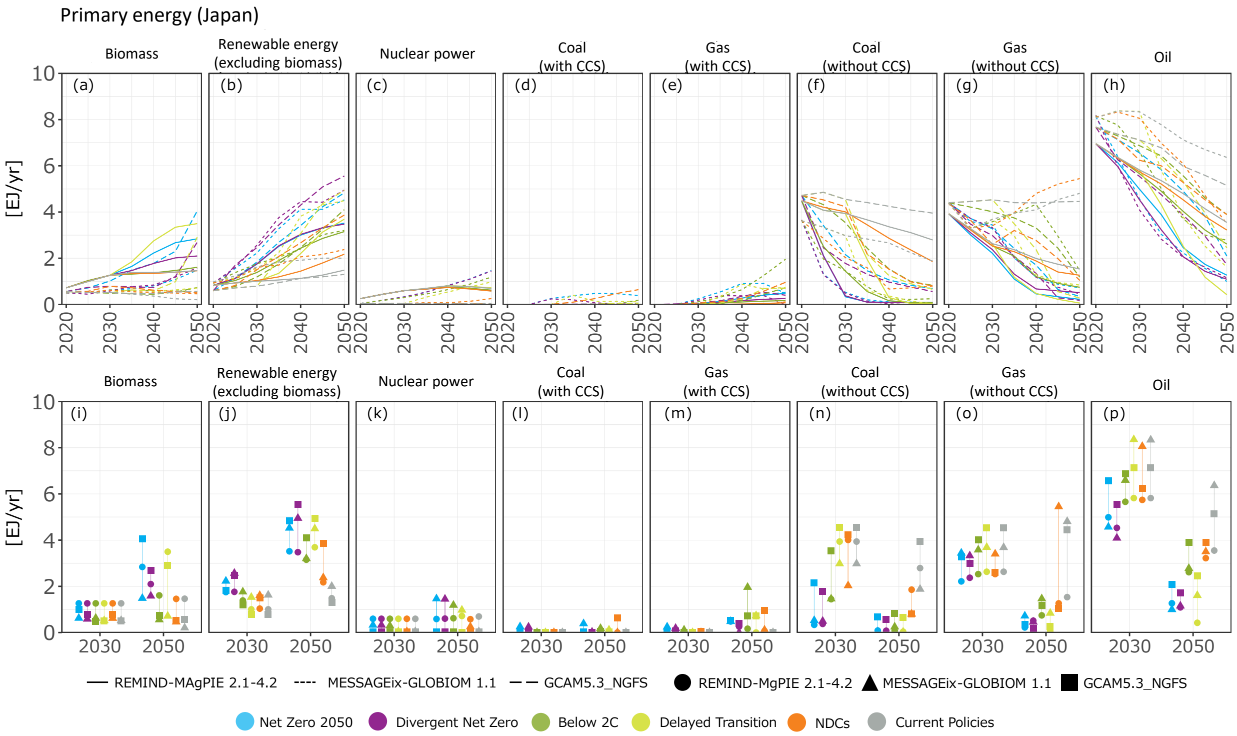


Figure 4.2.8 Pathways of primary energy by sector (upper row) and energy volumes in 2030 and 2050 (lower row)

4.2.6 Secondary Energy (Electricity Generation)

__Scenario characteristics common across the IAMs__

In line with the worldwide trend, the overall volume of electricity generation and the shares of renewable energy and nuclear energy in 2050 will be larger in scenarios that assume introduction of more ambitious emission reduction policies (Figure 4.2.9).

Net Zero 2050 and Divergent Net Zero (1.5ºC): The volume of electricity generation in 2050 will be the largest of all scenarios. Compared with the worldwide trend, the shares of solar power generation (■) and wind power generation (■) are large. Although both biomass power (■■) and nuclear power (■) will generate some volumes of electricity, their shares are small. The volume of fossil fuel electricity generation without CCS, which involves CO_2 emissions, in 2050 will fall to almost zero (Figure 4.2.9(a)(b)).

Below 2ºC and Delayed Transition (1.7ºC to 1.8ºC): Although the overall trend is similar to the trends in the above two scenarios, the overall volume of electricity generation will be slightly lower (Figure 4.2.9(c)(d)).

NDCs and Current Policies (2.5ºC to 3ºC+): The volume of electricity generation in 2050 will be the smallest of all scenarios. The shares of renewable energy, including solar power generation (■) and wind power generation (■) are small. On the other hand, even in 2050, some volume of fossil fuel electricity generation without CCS (■) will remain (Figure 4.2.9(e)(f)).

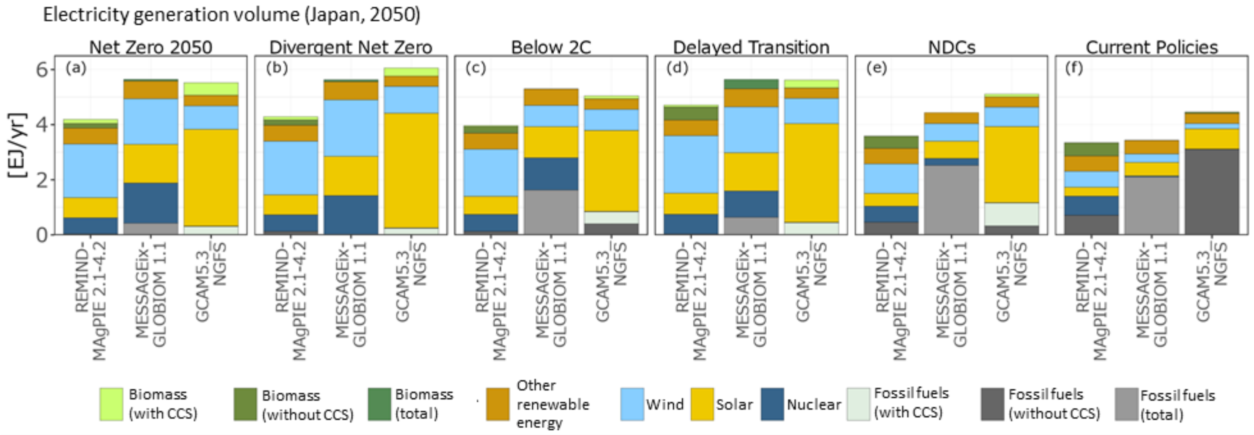


Figure 4.2.9 Breakdown of electricity generation volume in 2050 (Japan)

Differences between the IAMs

In Net Zero 2050, which assumes the introduction of the most ambitious emission reduction policy, there are characteristics distinctive to each of IAM with regard to the overall volume of electricity generation, solar power generation, wind power generation, nuclear power generation and the introduction of CCS.

REMIND-MAgPIE 2.1-4.2: In line with the worldwide trend, the volume of electricity generation will be the smallest of the three IAMs (Figure 4.2.9(a)). Compared with the worldwide trend, the volume of solar power generation (Figures 4.2.9 (a)■ and 4.2.10(e)(m)●) in both 2030 and 2050 will be small, while the volume of wind power generation (Figures 4.2.9 (a)■ and 4.2.10 (d)(l)●) will be correspondingly larger. The volume of nuclear power generation (Figures 4.2.9 (a)■ and 4.2.10 (f)(n)●) will remain constant in both 2030 and 2050.

MESSAGEix-GLOBIOM 1.1: In line with the worldwide trend, the volume of electricity generation will be at a medium level (Figure 4.2.9(a)). The volumes of solar power generation (Figures 4.2.9 (a)■ and 4.2.10 (e)(m)▲) and wind power generation (Figures 4.2.9 (a)■ and 4.2.10 (d)(l)▲) in 2050 will be similar to the worldwide trend. The share of nuclear power (Figures 4.2.9 (a)■ and 4.2.10 (f)(n)▲) is larger than the worldwide trend.

GCAM 5.3: In line with the worldwide trend, the volume of electricity generation will be the largest of the three IAMs (Figure 4.2.9(a)). The volume of wind power generation (Figures 4.2.9 (a)■ and 4.2.10 (d)(l)■) in 2050 will be small, while the volume of solar power generation (Figures 4.2.9 (a)■ and 4.2.10 (e)(m)■) in that year will be large. It should be noted that concentrated solar power (CSP) accounts for most of the volume of solar power generation.[9]

On the other hand, unlike at the worldwide trend, the volume of nuclear power generation (Figures 4.2.9 (a)■ and 4.2.10 (f)(n)■) will be almost zero. Some volume of CCS capacity will be introduced with respect to both biomass power generation (BECCS, Figures 4.2.9■ and 4.2.10(i)■) and fossil fuel electricity generation (Figures 4.2.9□ and 4.2.10 (f)(n)■).

[9] Concentrated solar power (CSP) refers to an electricity generation method that uses as a heat source solar light collected by lenses and reflectors at the solar furnace. In regions with sufficient sunlight (dry, low altitude regions), CSP will become a major renewable energy source. But in Japan, the potential for introducing CSP is limited. Therefore, the volume of electricity generation due to renewable energy reported for Japan under GCAM 5.3 is considered to be an overestimation.

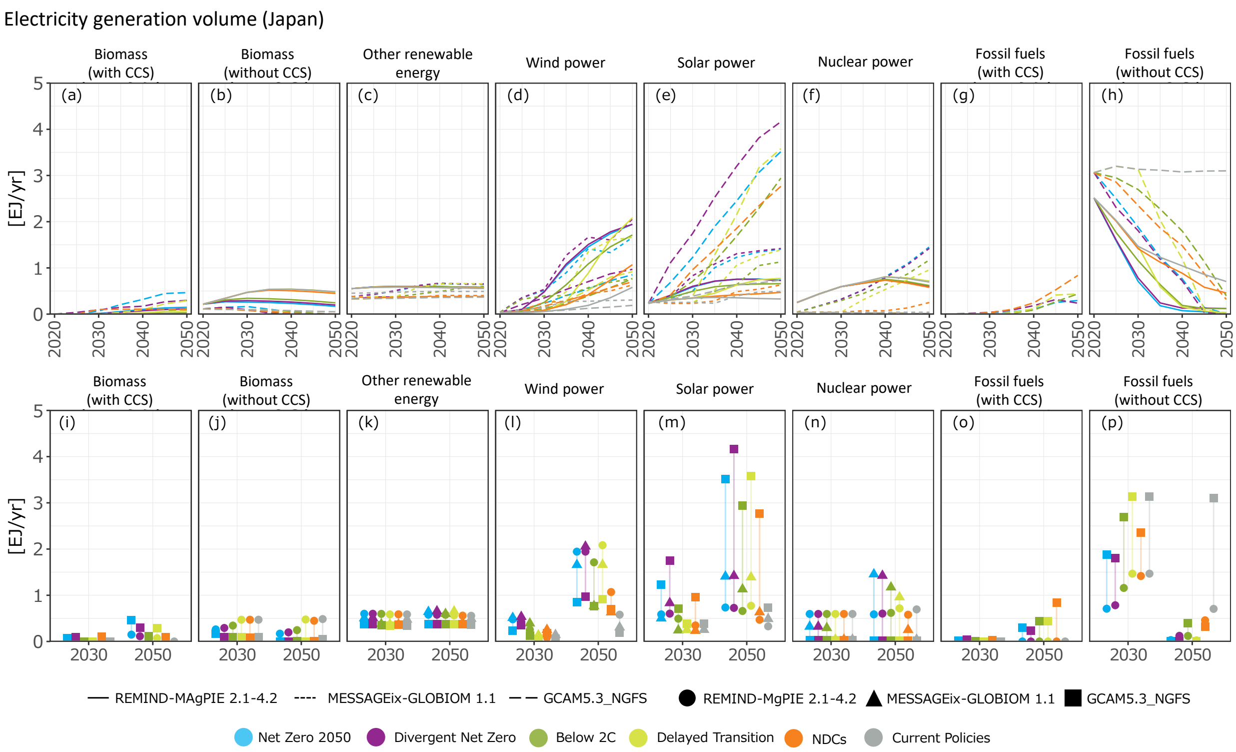


Figure 4.2.10 Changes in electricity generation volume (upper row) and electricity generation volume in 2030 and 2050 (lower row) (Japan)

4.2.7 Capital Cost

In line with the worldwide trend, there are few differences between the scenarios in terms of capital cost, so the figure below shows the assumptions of capital cost by type of power source in the Net Zero 2050 scenario. The general trend in Japan is similar to the worldwide trend, but under REMIND-MAgPIE 2.1-4.2, the capital cost of coal (with CCS) and nuclear power will be slightly higher compared with the worldwide trend (Figure 4.2.11).

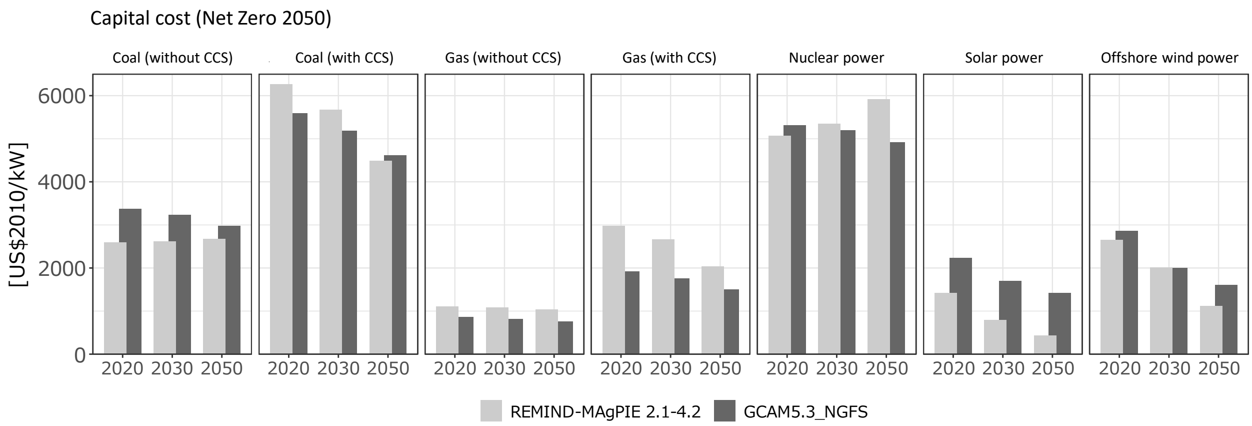


Figure 4.2.11 Assumed capital cost by electricity source (2020, 2030 and 2050) (Japan)

4.2.8 Final Energy

Scenario characteristics common across the IAMs

In line with the worldwide trend, electricity will have the largest share in final energy in 2050. On the other hand, the share of fossil fuels (gas, liquids, and solid) differs across the scenarios (Figure 4.2.12).

Net Zero 2050, Divergent Net Zero, Below 2ºC and Delayed Transition (1.5ºC to 1.8ºC): In these scenarios, all of which assume introduction of a policy intended to keep the temperature rise below 2ºC or lower, the overall volume of final energy consumption and the breakdown by type of energy in 2050 are almost the same. Electricity has a large share in final energy, while the share of fossil fuels is small (Figure 4.2.12 (a)-(d)).

NDCs and Current Policies (2.5ºC to 3ºC+): The volume of final energy consumption in 2050 will be slightly larger than in the above four scenarios, and the share of fossil fuels will also be larger. Under all of the IAMs, there will be some volume of residual consumption of coal in 2050 (Figure 4.2.12(e)(f); Under MESSAGEix-GLOBIOM 1.1, coal is included in solid fuels■).

Differences between the IAMs

In Net Zero 2050, which assumes introduction of the most ambitious emission reduction policy, there are characteristics distinctive to the IAMs in terms of the volume of final energy and the volume of fossil fuels in 2050.

REMIND-MAgPIE 2.1-4.2: In line with the worldwide trend, the volume of final energy will be smaller than under the other two IAMs (Figure 4.2.12(a)). Among fossil fuels, the volume of liquids (mainly oil) will be large (Figures 4.2.12 (a)■ and 4.2.13 (n)●).

MESSAGEix-GLOBIOM 1.1: The volume of final energy will be at a medium level (Figure 4.2.12(a)). The volume of gas (mainly natural gas), among fossil fuels, in 2050 will be the largest (Figures 4.2.12(a)■ and 4.2.13 (m)▲).The volume of liquids (mainly oil) will be the smallest (Figures 4.2.12 (a)■ and 4.2.13(n)▲), while there will be some volume of solid fuels (the total of coal and biomass) (Figures 4.2.12(a)■ and 4.2.13(p)▲).

GCAM 5.3: The volume of final energy will be the largest (Figure 4.2.12(a)). The volume of gas (Figures 4.2.12(a)■ and 4.2.13(m)■) in 2050 will be almost zero, while the volume of liquids (mainly oil) (Figures 4.2.12 (a)■ and 4.2.13 (n)■) will be at a medium level. In line with the worldwide trend, there will be some volume of residual consumption of coal in 2050 in all scenarios (Figures 4.2.12(a)■ and 4.2.13(o)■).

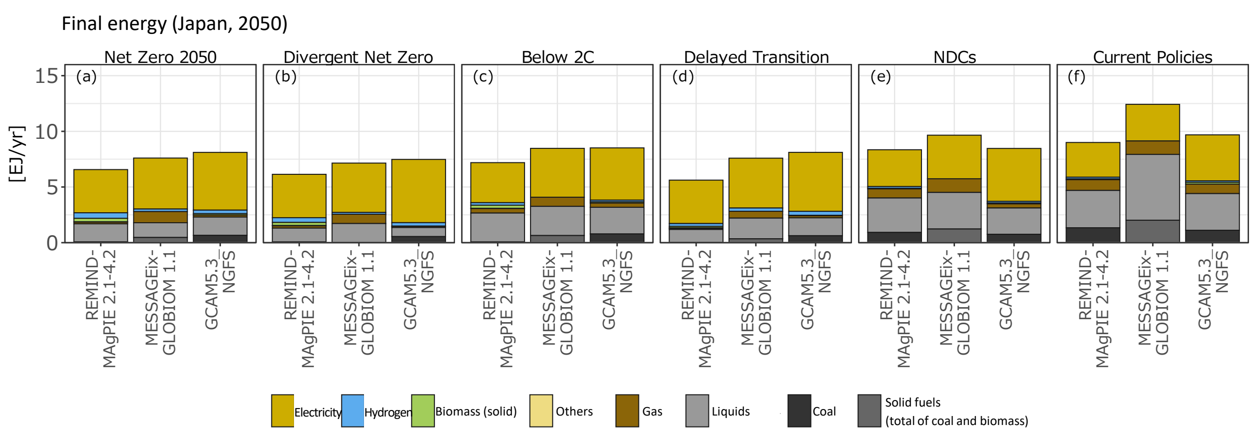


Figure 4.2.12 Breakdown of final energy by type of energy in 2050 (Japan)

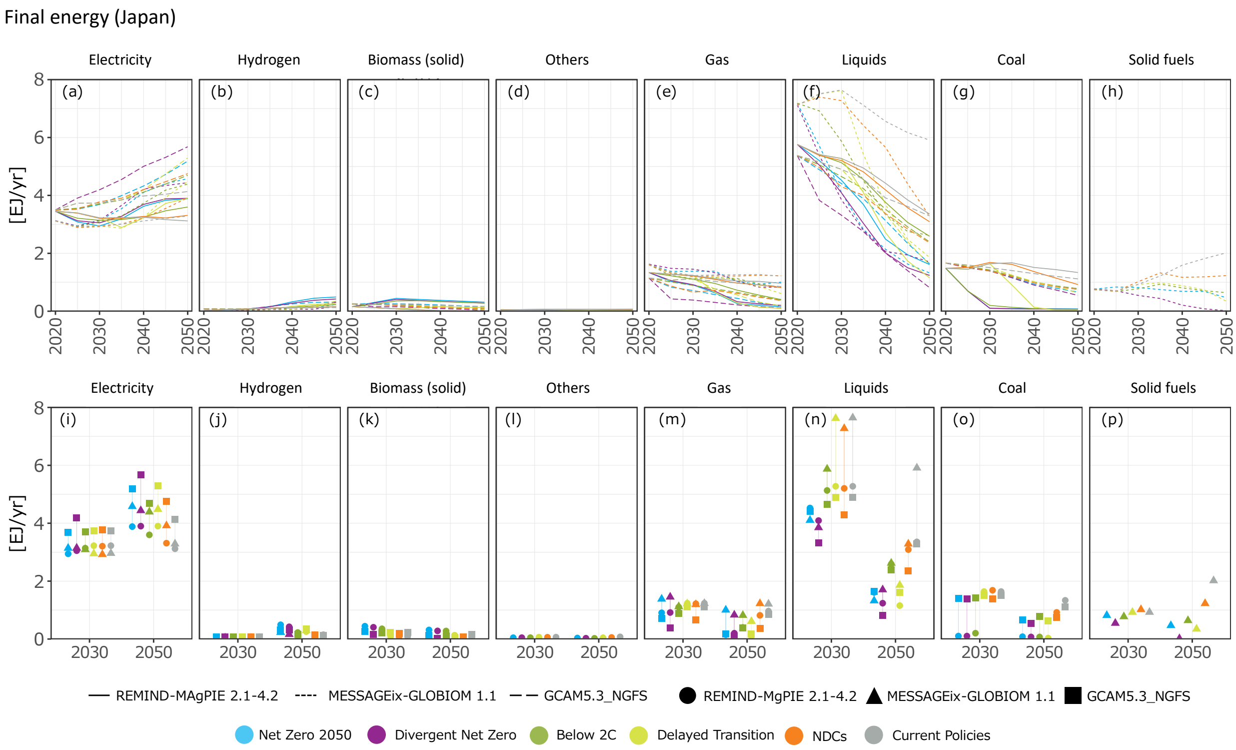


Figure 4.2.13 Pathways of final energy demand (upper row) and demand volume in 2030 and 2050 (lower row) (Japan)

4.2.9 Energy Prices (Rate of change compared with 2020)

Energy prices in 2020 (Japan)

There are differences between the IAMs in energy prices in Japan in 2020 (the differences in oil and electricity prices are particularly large) in line wih the worldwide trend. Therefore, this section looks at changes in terms of energy price indexes compared with 2020, rather than the absolute levels of energy prices.

It should be noted that the figures for Japan under MESSAGEix-GLOBIOM 1.1 are ones downscaled from the original regional category in the model and that the assumptions underlying the calculation are different from the ones used in the other IAMs, which assign Japan as a native regional category. In addition, regarding the downscaled figures, price variables are uniform among countries within the native regional category, rather than being adjusted, unlike variables such as energy consumption. Indeed, under MESSAGEix-GLOBIOM 1.1, Japan is placed in the same regional category as Australia and New Zealand, and the energy prices reported for these three countries are the same.

Scenario characteristics common across the IAMs

Although some primary energy prices differ extremely across the scenarios or across the IAMs, the differences between the IAMs are smaller in Japan compared with the worldwide trend. The coal price will decline in a majority of scenarios. Regarding the gas price, an uptrend towards 2030 and 2050 is common across all scenarios except in some periods in Delayed Transition. The oil price will rise in many scenarios. Regarding the electricity price, the rate of increase is conspicuously higher in Japan in all scenarios compared with the worldwide trend (Figure 4.2.14).

Net Zero 2050 (1.5ºC), Divergent Net Zero (1.5ºC), and Below 2ºC (1.7ºC): In line with the worldwide trend, the gas price will rise more in scenarios that assume introduction of more ambitious emission reduction policies (Figure 4.2.14(f)). The oil price shows an uptrend while the coal price shows a downtrend, although the rate of change varies across the IAMs (Figure 4.2.14(e)(g)). The electricity price will rise towards 2030 (Figure 4.2.14(d)(h)).

Delayed Transition (1.8ºC): In line with the worldwide trend, there is no consistency in terms of movements of gas, coal and oil prices, with all those prices showing either an uptrend or downtrend depending on the IAM. The prices differ extremely across the IAMs. The electricity price will temporarily rise in 2035-2040 (Figure 4.2.14(d)(h)).

NDCs and Current Policies (2.5ºC to 3ºC+): Compared with the above four scenarios, which assume introduction of an emission reduction policy, the rate of changes in prices is smaller. The gas and oil prices will rise (Figure 4.2.14(e)(f)). The coal price will either rise or decline depending on the IAM (Figure 4.2.14(e)). The rate of change in the electricity price is smaller than in the above four scenarios (Figure 4.2.14(d)(h)).

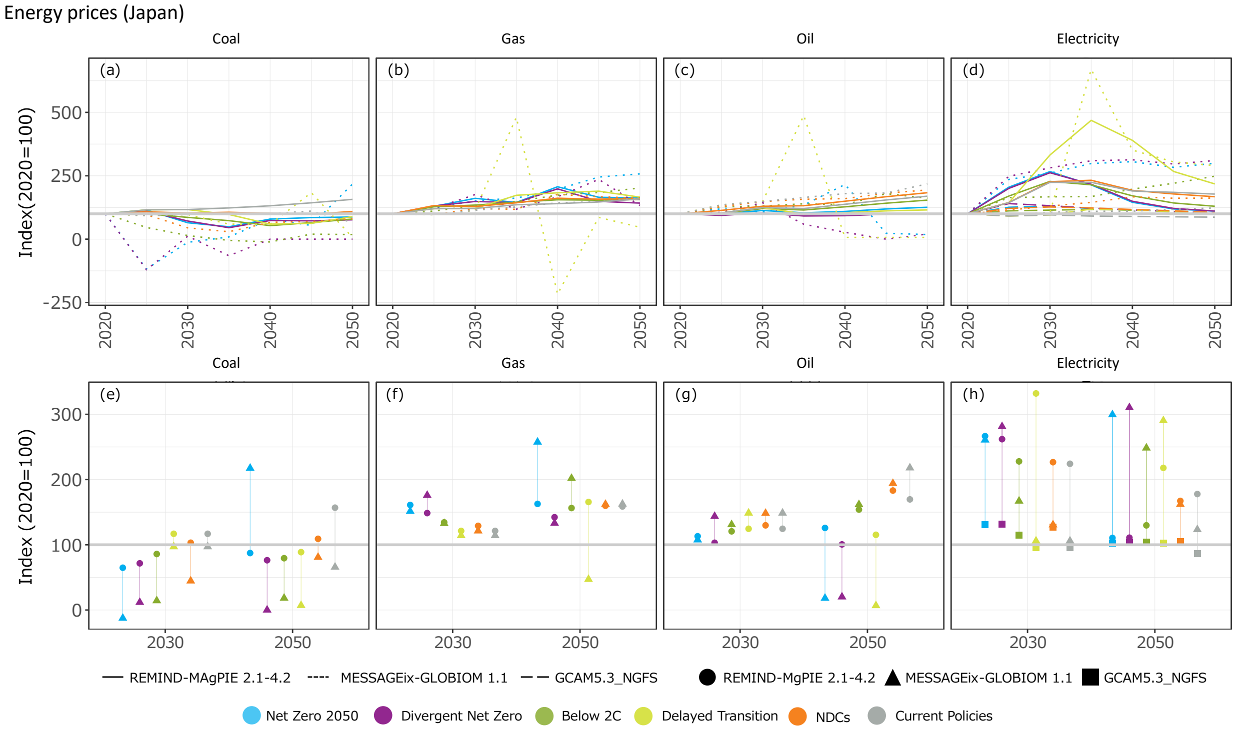
<u>Differences between the IAMs</u>

In line with the worldwide trend, the rate of change in fossil fuel prices differs distinctively across the IAMs. The prices show either a temporary uptrend or downtrend depending on the IAM.

REMIND-MAgPIE 2.1-4.2: The rate of change in fossil fuels is small. The electricity price will rise significantly in Net Zero 2050, Divergent Net Zero and Delayed Transition, reaching its peak in 2030 in the first two scenarios and in 2040 in the last one, and then decline towards 2050 (Figure 4.2.14 (d)●●●).

MESSAGEix-GLOBIOM 1.1: Compared with the other two IAMs, fossil fuel prices will show extreme fluctuations, recording a higher rate of change. In Net Zero 2050, Divergent Net Zero, Below 2ºC, and Delayed Transition, the rate of change in electricity price in 2050 will be higher compared with the other two IAMs (Figure 4.2.14 (h)▲▲▲▲). However, the higher rate of change may be attributable in part to the fact that the electricity price in 2020 is lower compared with the other two IAMs.

GCAM 5.3: With respect to Japan, there is no report on primary energy prices (fossil fuels). The rate of change in the electricity price is small (Figure 4.2.14 (h)■).



* Under MESSAGEix-GLOBIOM 1.1, the coal and gas prices are negative in some cases, but the negative prices are considered to be price calculation errors.

Figure 4.2.14 Pathways of energy prices (upper row) and price levels in 2030 and 2050 (lower row) (Japan)

4.2.10 Energy Investment (cumulative total until 2050)

In line with the worldwide trend, the value of investment in fossil fuel electricity generation will be smaller and the value of investment in renewable energy (solar and wind power) and nuclear power will be larger in scenarios that assume more ambitious emission reduction policies. In addition, the value of investment in electricity transmission and distribution will be large (Figures 4.2.15 and 4.2.16).

Differences between the IAMs

REMIND-MAgPIE 2.1-4.2: Compared with the worldwide trend, the value of investment in wind power generation relative to investment in other types of energy will be larger. Unlike the worldwide trend, the value of investment in nuclear power generation will be at a high level (Figures 4.2.15 and 4.2.16●).

MESSAGEix-GLOBIOM 1.1: (There is no report on figures for Japan)

GCAM 5.3: In line with the worldwide trend, the value of investment in fossil fuel electricity generation will be large while the value of investment in wind power will be small. On the other hand, unlike the worldwide trend, the value of investment in electricity transmission and distribution will be higher than under REMIND-MAgPIE 2.1-4.2 (Figures 4.2.15 and 4.2.16■).

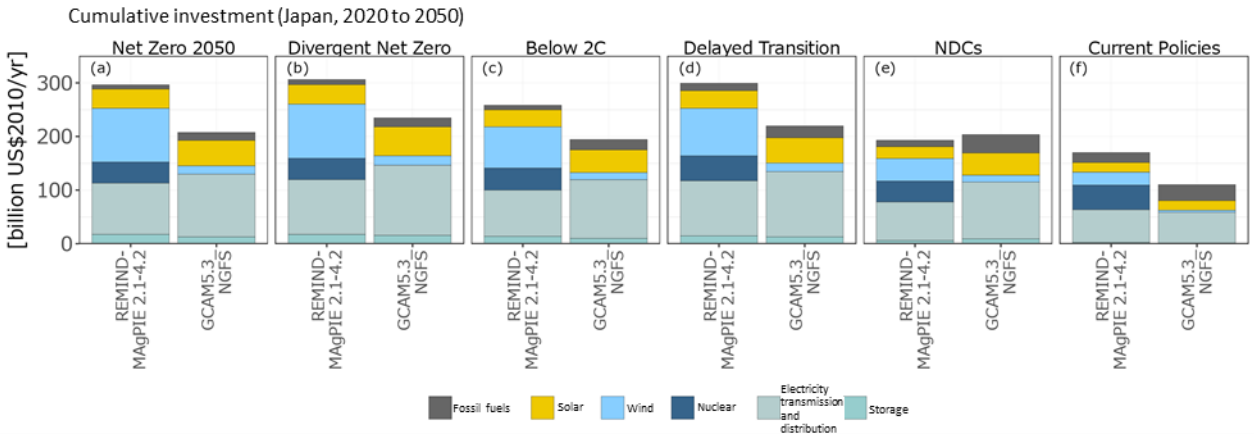


Figure 4.2.15 Cumulative energy-related investment (2020-2050) (Japan)

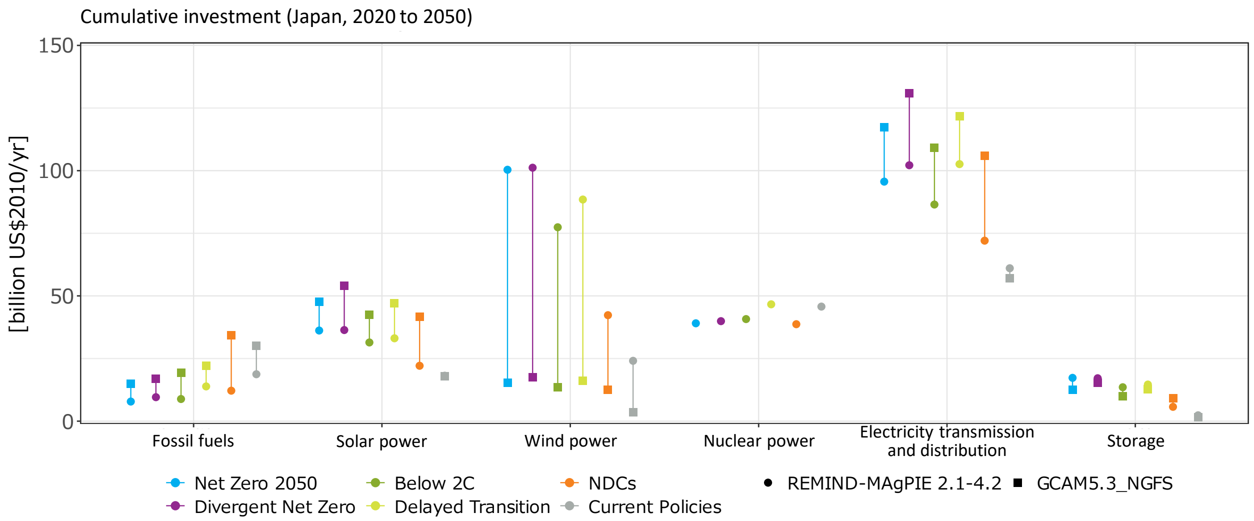


Figure 4.2.16 Cumulative energy-related investment (2020-2050, by sector) (Japan)

4.2.11 Summary: Characteristics of the NGFS Scenarios for Japan

Achievement of negative emission and CO_2 removal technology

In line with the worldwide trend, in Japan, the share of non-fossil energy (the combined share of renewable energy and nuclear power) in electricity generation volume (the non-fossil share in the electricity power source mix) in 2050 will be large (Figure 4.2.9), and the share of electricity in final energy (electricification rate) will also be high (Figure 4.2.12) in scenarios that assume the introduction of ambitious emission reduction policies. This indicates that under the NGFS Scenarios (Phase 2Phase 2), combining the electrification of final energy consumption and decarbonization of electricy generation will reduce the volume of energy-related CO_2 emisions (Figure 4.2.17).

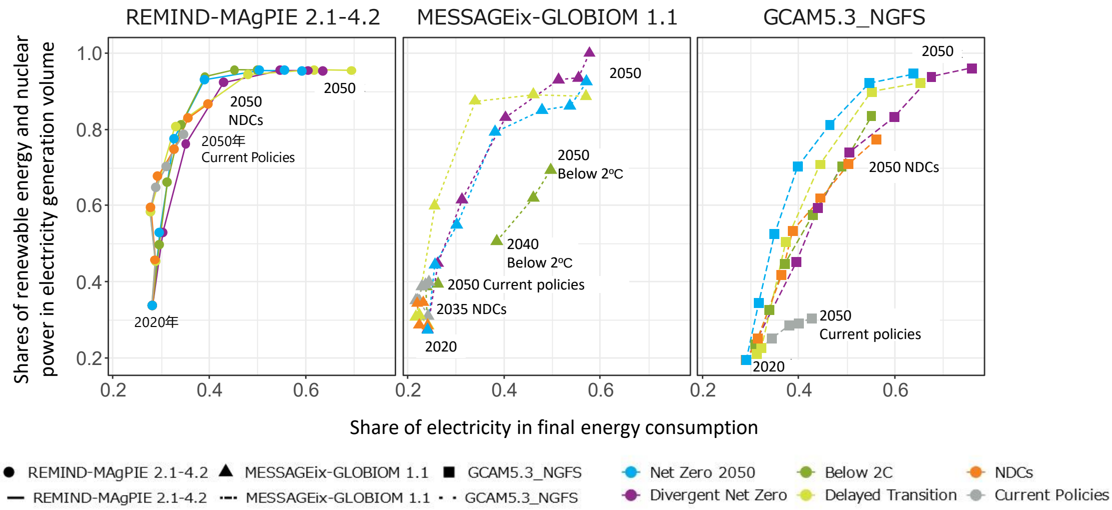


Figure 4.2.17 Relationship between the share of electricity in final energy consumption (electrification rate) and share of non-fossil electricity sources (renewable energy electricity generation and nuclear power generation) in electricity generation (the non-fossil fuel share in the electricity source mix); changes between 2020 and 2050 (figures for every five years) (Japan)

On the other hand, in Net Zero 2050, for example, the volume of CO_2 emissions in the world in 2050 will be almost zero (net zero), whereas the volume of CO_2 emissions in Japan in that year may be negative on a net basis depending on the IAM (Figure 4.2.1). Although there will be residual emissions in the industrial and transport sectors, the volume of negative emissions will be sufficient to more than offset them (Figure 4.2.3 (a)). Negative emissions in Japan are attributable mainly to CO_2 removals by BECCS, while CO_2 removals by afforestation are close to zero (Figure 4.2.5).

An increase in BECCS capacity due to ambitious emission reduction policies, such as the policy assumed in Net Zero 2050, will affect demand for biomass fuels. Regarding primary energy in 2050, the share of biomass in Japan will be slightly larger compared with the worldwide trend (Figure 4.2.7). An increase in BECCS capacity will lead to an increase in imports of biomass. Figure 4.2.18 shows changes in the volume of CO_2 removals due to BECCS and in the share of imported biomass in Japan from 2020 to 2050 under REMIND-MAgPIE 2.1-4.2, which provides a report on the import volume of biomass. In scenarios that assume introduction of an ambitious emission reduction policy, the share of imported biomass will increase towards 2050 in line with an increase in the volume of CO_2 removals due to BECCS.

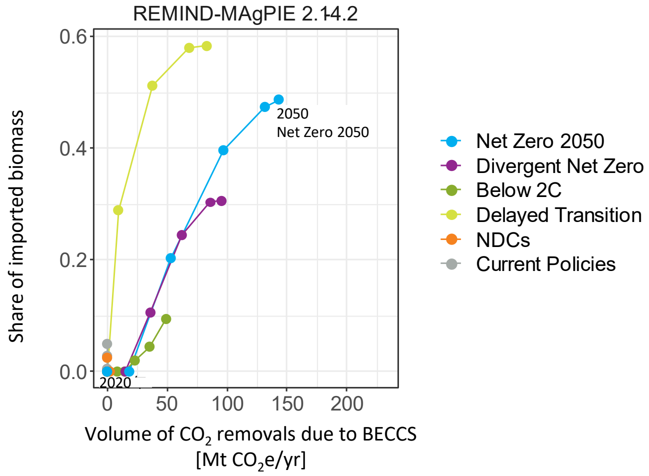


Figure 4.2.18 Changes in the volume of CO_2 removals due to BECCS and in the share of imported biomass from 2020 to 2050 (figures for every five years) (Japan)

Changes in energy prices and factors of change

There are not clear differences between the scenarios in terms of energy prices, but extreme price fluctuations are observed in some cases. Cases in point regarding Japan include the gas price trend under MESSAGEix-GLOBIOM 1.1 and the electricity price trend under REMIND-MAgPIE 2.1-4.2 (Figure 4.2.14).

Under the IAMs, the prices of oil and gas, which are primary energy, reflect the dynamics of the oil and gas market in a state of long-term equilibrium, so they are calculated under an approach disconnected from the mechanism that determines prices in the real world.[10] Under this calculation approach, factors such as the resource exploitation cost, fuel demand, and climate policy affect prices through the optimization of objective function in the IAM. As a result, it is difficult to identify the decisive factor of gas price changes under MESSAGEix-GLOBIOM 1.1.

Under REMIND-MAgPIE 2.1-4.2, secondary energy prices are also calculated under the same approach as the one used for the calculation of primary energy prices. Under this IAM, the electricity price will decline towards 2050 after rapidly rising around 2030 (Figure 4.2.14(d)). As the price rise occurs in a period when low-carbon power sources expand, the price rise may be attributable to the effects of capital investments related to such power sources.[11]

Indeed, as shown in Figure 4.2.19, the electricity price will show significant price fluctuations in line with significant changes in the value of electricity-related investments under REMIND-MAgPIE 2.1-4.2. In particular, the rate of change in the value of investment related to wind power and electricity transmission and distribution is high. The value of investment related to wind power will increase and reach its peak first, followed by the peaking of the value of investment in electricity transmission and distribution. For convenience of comparison, Figure 4.2.19 also shows the results for

[10] This applies to REMIND-MAgPIE 2.1-4.2 and MESSAGEix-GLOBIOM 1.1 (NGFS FAQ https://www.ngfs.net/ngfs-scenarios-portal/faq#high-oil-prices). According to the disclosed source code of these IAMs, primary energy prices have been defined in a way that links changes in the energy balance at the optimized point of intertemporal optimization to changes in cost.

[11] In REMIND-MAgPIE 2.1-4.2, electricity price is derived from macro-economic income identity and electricity balance equations. In this case, it is presumed that when the change in the value of investment is large relative to the change in electricity demand, such changes may be reflected to electricity price.

GCAM 5.3. Under this IAM as well, investments are concentrated in a certain period in some scenarios, but that is not reflected in the electricity price. Unlike IAMs with inter-temporal optimization, GCAM 5.3 calculates prices so as to balance supply and demand in regional and sectoral markets without having perfect foresights (Box 1). In this case, significant price fluctuations are unlikely to occur.

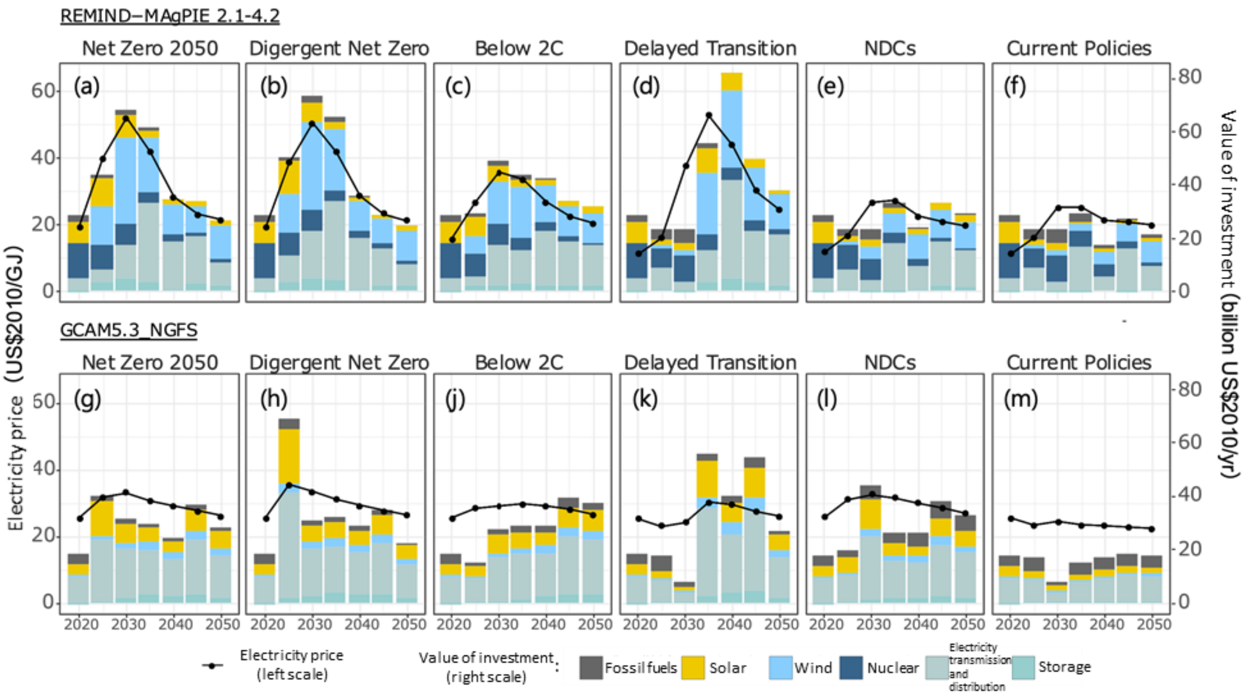


Figure 4.2.19 Comparison of electricity price and value of electricity-related investments (Japan)

4.3 Overview of the NGFS Scenarios (Phase 2): Characteristics of major regions

This section examines the characteristics of regions through inter-regional comparison of the key variables of the NGFS Scenarios (Phase 2). The regions compared are Japan, the EU, the United States, China, India, and Indonesia (Table 4.3.1). The EU and the United States are relatively large CO_2 emitters with a large GDP size among advanced economies. Meanwhile, China and India have relatively large shares in global CO_2 emissions among emerging economies and are expected to see an increase in CO_2 emissions due to economic growth. Indonesia, with its large population size, is considered to be the representative CO_2 emitter of Southeast Asia. In this section, for the sake of convenience, Japan, the EU, and the United States are referred to as "advanced economies" and China, India and Indonesia as "emerging economies."

Table 4.3.1 Regions for analysis in this section and categories in NGFS Scenarios (Phase 2)

Region	REMIND-MAgPIE 2.1-4.2	MESSAGEix-GLOBIOM 1.1	GCAM5.3
Japan	Native regional category	Data downscaled from Pacific OECD	Native regional category
EU	Native regional category	Native regional category	Native regional category
U.S.	Native regional category	Native regional category	Native regional category
China	Native regional category	Native regional category	Native regional category
India	Native regional category	Native regional category	Native regional category
Indonesia	Data downscaled from OAS (Other Asian Countries)	Data downscaled from PAS (Other Pacific Asia)	Native regional category

When selecting the regions for analysis, we took into consideration whether there is a native regional category for the regions under the IAMs adopted in the NGFS Scenarios (Phase 2). However, regarding Japan and Indonesia, there is no native regional category under some IAMs. In that case, we analyzed data downscaled from the regional level to the country level (Table 4.3.1).

This section focuses mainly on the Net Zero 2050 scenario, which assumes introduction of the most ambitious emission reduction policy among the six scenarios included in the NGFS Scenarios (Phase 2), and the Current Policies scenario, which assumes introduction of the least ambitious emission policy (regarding the carbon price, the Delayed Transition scenario is also looked at as a reference).

4.3.1 CO_2 Emissions

In all regions, there is a significant difference between Net Zero 2050 and Current Policies in terms of CO_2 emission volume. This means that the current emission reduction policies have a large gap to fill if net zero emissions are to be achieved.

<u>**Characteristics of the regions**</u>

Japan, the EU and the United States (advanced economies): In both Net Zero 2050 and Current Policies, CO_2 emission volume will decline towards 2050 (in the EU's case alone, the emission volume shows a slight uptrend in Current Policies under MESSAGEix-GLOBIOM 1.1). In Net Zero 2050, net zero emissions—or even net negative emissions depending on the IAM—will be achieved (Figure 4.3.1(a)-(c)).

China, India and Indonesia (emerging economies): In Net Zero 2050, although significant emission reduction is expected after 2020, net zero emissions will not be achieved by 2050. In Current Policies, CO_2 emission volume will stay almost flat or increase slightly (Figure 4.3.1(d)-(f)).

Differences between the IAMs

Regarding Indonesia, there is a significant difference in terms of CO_2 emission volume between REMIND-MAgPIE 2.1-4.2 and MESSAGEix-GLOBIOM 1.1 on the one hand and GCAM 5.3 on the other (Figure 4.3.1(f)). This is considered to reflect the effects of the downscaling of data from the regional level "other Asia" under REMIND-MAgPIE 2.1-4.2 and MESSAGEix-GLOBIOM 1.1.

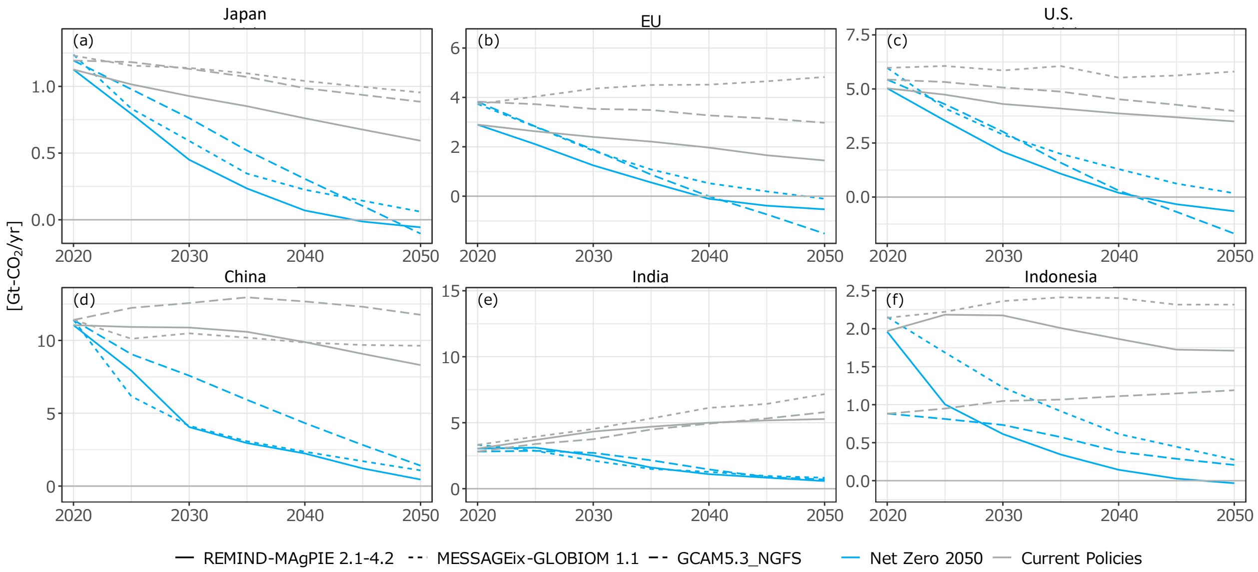


Figure 4.3.1 Trend in CO_2 emissions in major regions

4.3.2 CO_2 Emissions by Sector

Characteristics of the regions

Japan, the EU and the United States (advanced economies): In line with the worldwide trend, emission volume in 2050 will decline significantly, mainly in the industrial sector■, in Net Zero 2050. CO_2 emission volume will become negative in the energy supply sector (electricity■ and others■) (Figure 4.3.2(c)(f)(i)).

China and India (emerging economies): In Net Zero 2050, emission volume in 2050 will decline in the industrial sector, as in advanced economies. However, emission volume will become negative in fewer sectors than in advanced economies (Figure 4.3.2(l)(o)).

Indonesia (emerging economy): In Net Zero 2050, emission volume in 2050 will decline in the industrial sector and become negative in a few sectors, as in the other emerging economies. In all scenarios, the share of the AFOLU sector (land use)■ in CO_2 emissions/negative emissions is larger than in advanced economies (Figure 4.3.2(p)(q)(r)).

Differences between the IAMs

With respect to Indonesia, emission volume in the AFOLU sector (land use) will be larger under REMIND-MAgPIE 2.1-4.2 and MESSAGEix-GLOBIOM 1.1 than under GCAM5.3. This is considered to reflect the effects of downscaling of data from the regional level "other Asia."

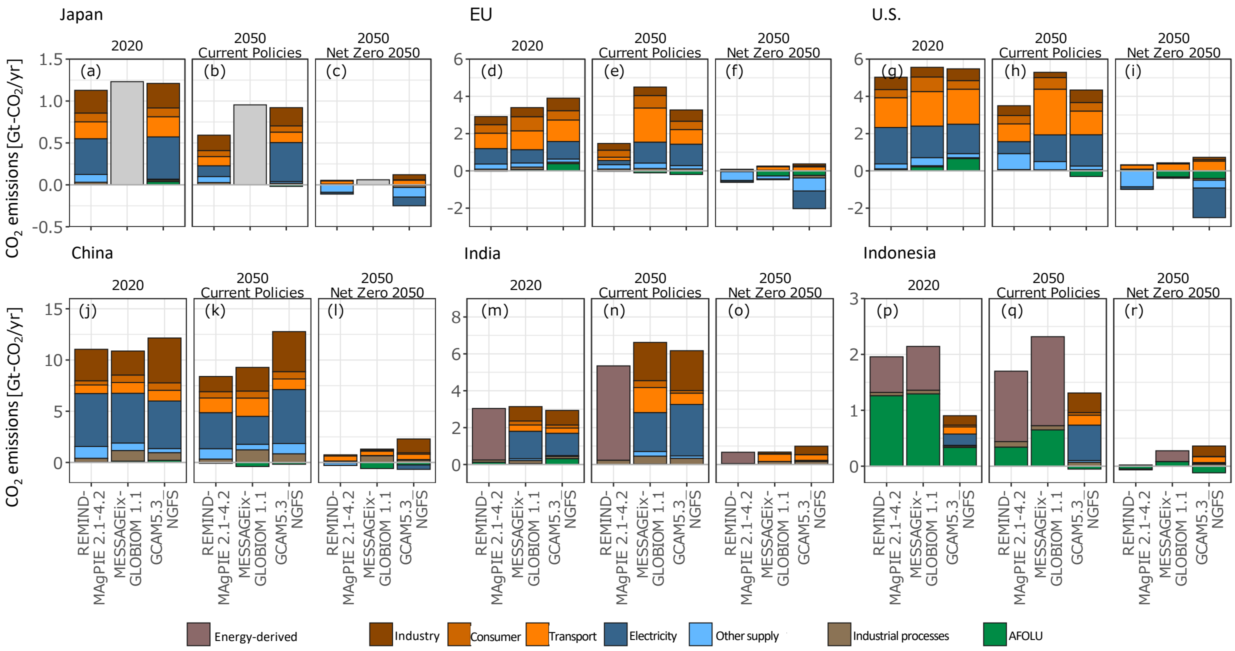


Figure 4.3.2 CO_2 Emissions by sector in major regions

4.3.3 Carbon Prices

In all regions, the carbon price will rise towards 2050 in scenarios that assume introduction of ambitious emission reduction policies (Net Zero 2050 and Delayed Transition), while it will not rise in the Current Policies scenario, which does not assume introduction of an ambitious emission reduction policy. In all scenarios, the margin of increase in the carbon price will be larger in advanced economies than in emerging economies, indicating that there are regional differences in terms of the intensity of the emission reduction policy.

It should be noted that whether the carbon price will rise higher in Net Zero 2050 or in Delayed Transition will vary depending on the region and the IAM.

<u>**Characteristics of the regions**</u>

Japan, the EU and the United States (advanced economies): In line with the worldwide trend, the carbon price will rise higher towards 2050 in scenarios that assume introduction of more ambitious emission reduction policies (Net Zero 2050 and Delayed Transition). The margin of increase in carbon prices in Delayed Transition will be larger than in emerging countries and the carbon price in 2050 in that scenario will be above the level in Net Zero 2050 under all IAMs (Figure 4.3.3(a)(b)(c)(g)(h)(i)).

China and Indonesia (emerging economies): In Delayed Transition, the margin of increase in the carbon price in 2050 will be smaller than in advanced economies and the carbon price will remain at the same level as in Net Zero 2050 (Figure 4.3.3(d)(f)(j)(l)).

India (emerging economy): The margin of increase in the carbon price will be low in Net Zero 2050. However, in Delayed Transition, the margin of increase in the carbon price after 2030 will be large, resulting in a significant difference between the carbon price levels in 2050 in these two scenarios. (Figure 4.3.3(e)(k)).

Characteristics of the IAMs

Under MESSAGEix-GLOBIOM 1.1, the regional variance in the carbon price is larger than under the other IAMs. In the EU in particular, the carbon price in 2050 will be far higher than in other regions in both Net Zero 2050 and Delayed Transition (Figure 4.3.3 ▲ ▲).

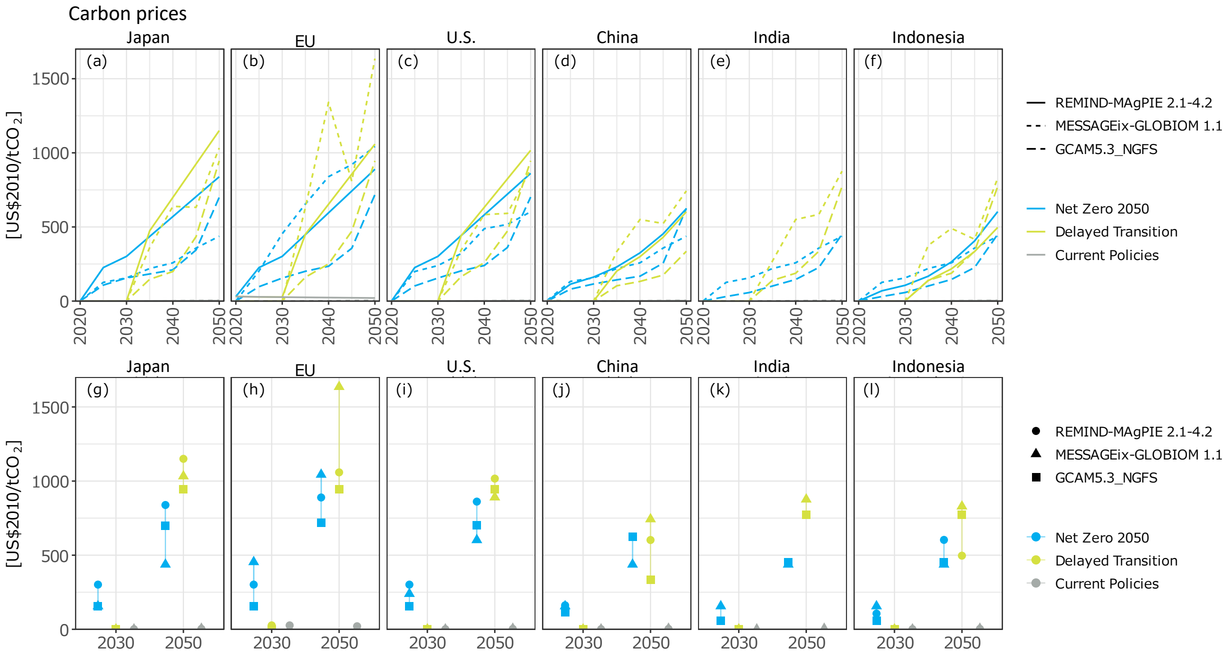


Figure 4.3.3 Trend in carbon prices in major regions

4.3.4 CO_2 Removals

In all regions, some volume of CO_2 removal technology capacity (BECCS and afforestation) will be introduced by 2050 in Net Zero 2050. It should be noted that there are larger differences between the IAMs than between the regions in terms of the type and volume of CO_2 removal technology capacity introduced (Figure 4.3.4).

Differences between the IAMs

REMIND-MAgPIE 2.1-4.2: In line with the worldwide trend, among the BECCS technologies, BECCS (liquids)■, BECCS (hydrogen)■, and BECCS (industry)■ have large shares.

MESSAGEix-GLOBIOM 1.1: In line with the worldwide trend, the share of CO_2 removals due to afforestation■ is large.

GCAM 5.3: In line with the worldwide trend, CO_2 removal volume under this model is the largest of the three IAMs, and the share of BECCS (electricity)■ is large. It should be noted that GCAM 5.3 does not provide a report on CO_2 removal volume due to afforestation, and therefore, the actual CO_2 removal volume is presumed to be larger.

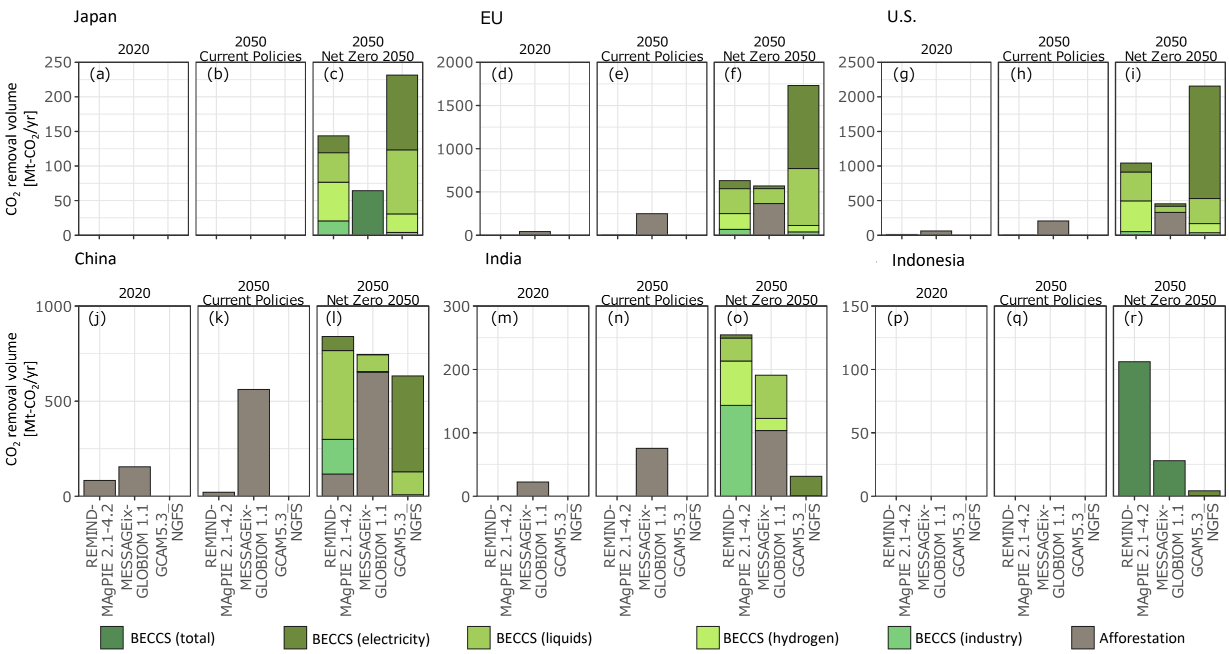


Figure 4.3.4 CO_2 removal capacity introduced in major regions

4.3.5 Primary Energy

In Net Zero 2050, the share of fossil fuels in 2050 will decline, while the shares of renewable energy and nuclear power will increase.

Characteristics of the regions

Japan, the EU and the United States (advanced economies): Compared with the trend in emerging countries, the share of fossil fuels in 2050 in Net Zero 2050 will be smaller. Among the renewable energies, biomass■ has a relatively large share. (Figure 4.3.5 (c)(f)(i)).

China, India and Indonesia (emerging economies): In Net Zero 2050, the share of fossil fuels in 2050 will decline but will still remain larger than in advanced economies. In addition, although the share of fossil fuels with CCS (coal□ and gas■) in overall energy consumption will be small, it will be slightly larger than in advanced economies (Figure 4.3.5 (l)(o)(r)).

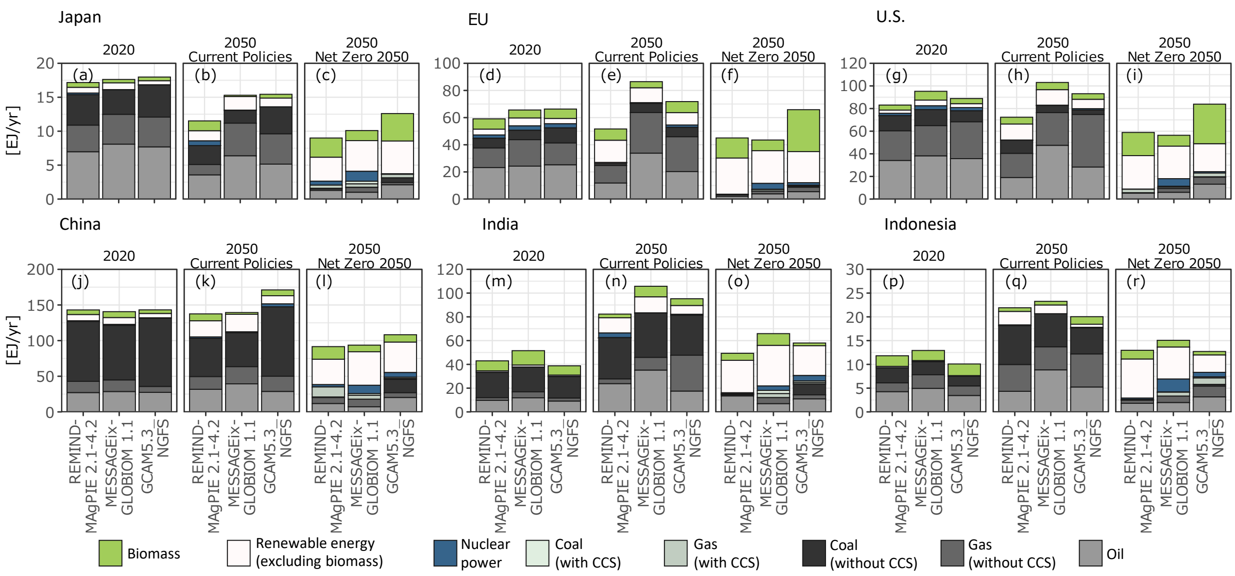


Figure 4.3.5 Breakdown of primary energy in major regions

4.3.6 Electricity Generation (Secondary Energy)

In line with the worldwide trend, overall electricity generation volume and the shares of renewable energy and nuclear power will increase towards 2050 in Net Zero 2050, but the type of technology introduced will vary across the regions and across the IAMs.

Characteristics of the regions

In Net Zero 2050, solar power generation and wind power generation will have the largest shares in 2050 in all regions, but regarding other types of electricity generation technology, there will be regional disparities.

Japan, the EU and the United States (advanced economies): In Net Zero 2050, the share of biomass with CCS■ will be relatively large in 2050 (Figure 4.3.6(c)(f)(i)).

China, India and Indonesia (emerging economies): In Net Zero 2050, the share of fossil fuel with CCS□ will be relatively large (Figure 4.3.6(l)(o)(r)).

Differences between the IAMs

REMIND-MAgPIE 2.1-4.2: In both Net Zero 2050 and Current Policies, solar power generation and wind power generation will grow significantly. The share of fossil fuels in Current Policies will be the smallest of the three IAMs.

MESSAGEix-GLOBIOM 1.1: In line with the worldwide trend, the volume of nuclear power will be larger than under the other IAMs. However, in Indonesia (downscaled from the regional level "other Asia-Pacific region"), the share of nuclear power in 2050 will rise to around 40% in Net Zero 2050 (Figure 4.3.6(r)).

GCAM 5.3: In Net Zero 2050, the share of biomass with CCS under this IAM will be the largest of the three IAMs in advanced economies (Japan, the EU and the United States) and China, indicating that CO_2 removal technology will be deployed in the electricity generation sector (Figure 4.3.6(c)(f)(i)(l)).

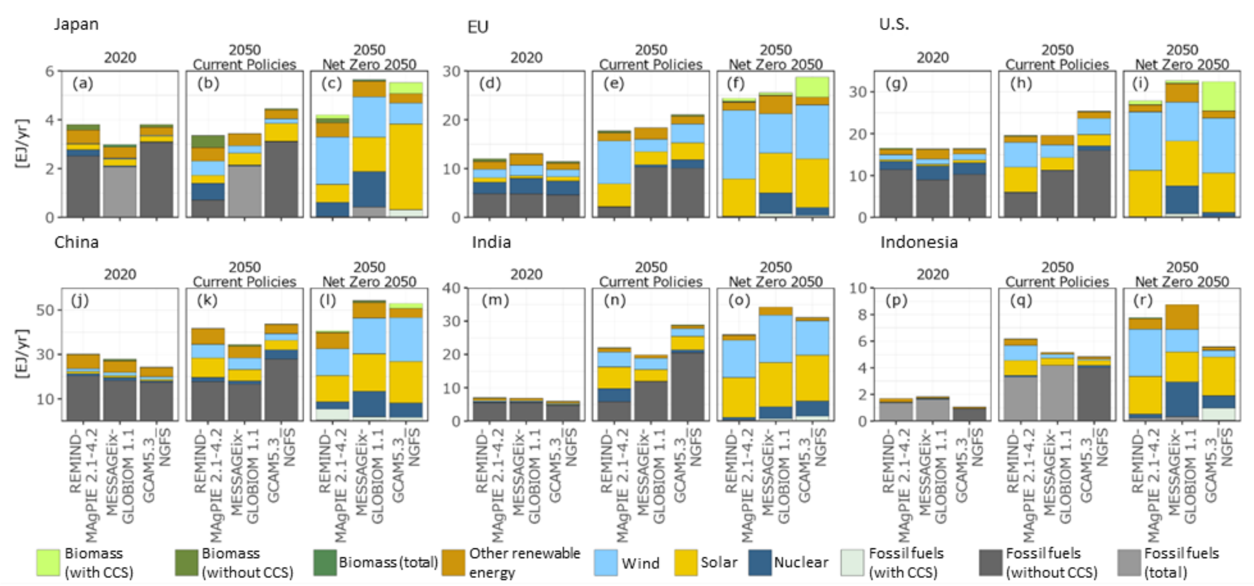


Figure 4.3.6 Breakdown of electricity generation volume in major regions

4.3.7 Final Energy

In Net Zero 2050, overall final energy consumption in 2050 will decline and the share of electricity generation will increase in all regions (Figure 4.3.7).

<u>**Differences between the IAMs**</u>

REMIND-MAgPIE 2.1-4.2: Overall final energy consumption will be small compared with other IAMs power generation.

MESSAGEix-GLOBIOM 1.1: The share of coal will be small compared with the other IAMs, while the share of liquid fuels will be large.

GCAM 5.3: Even in Net Zero 2050, there will be residual coal consumption in 2050.

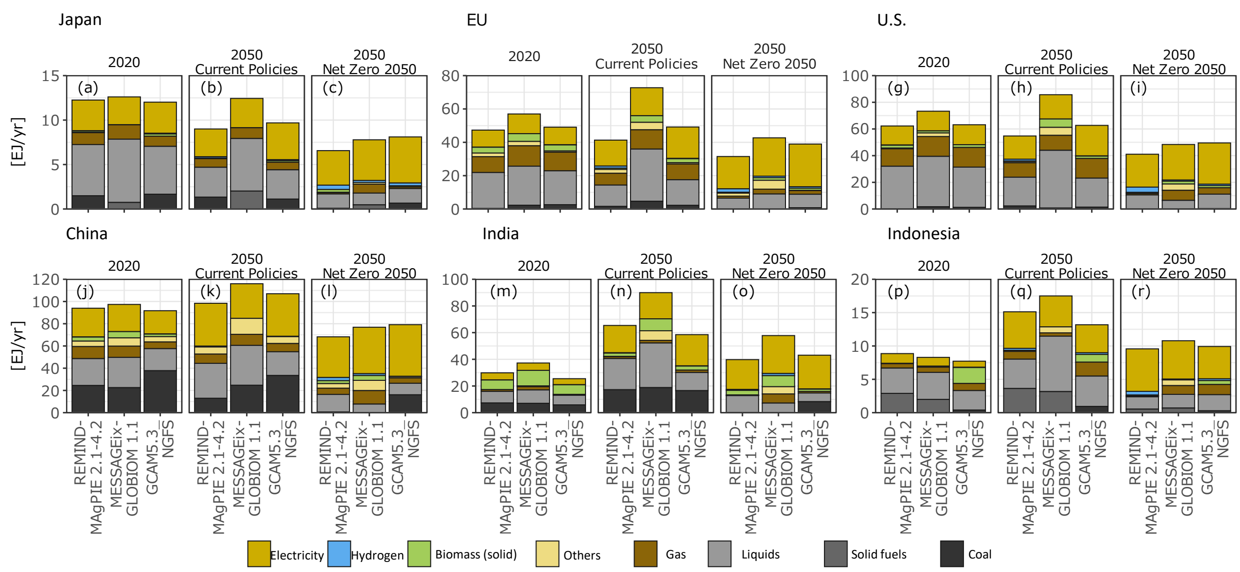


Figure 4.3.7 Breakdown of final energy in major regions

4.3.8 Energy Prices

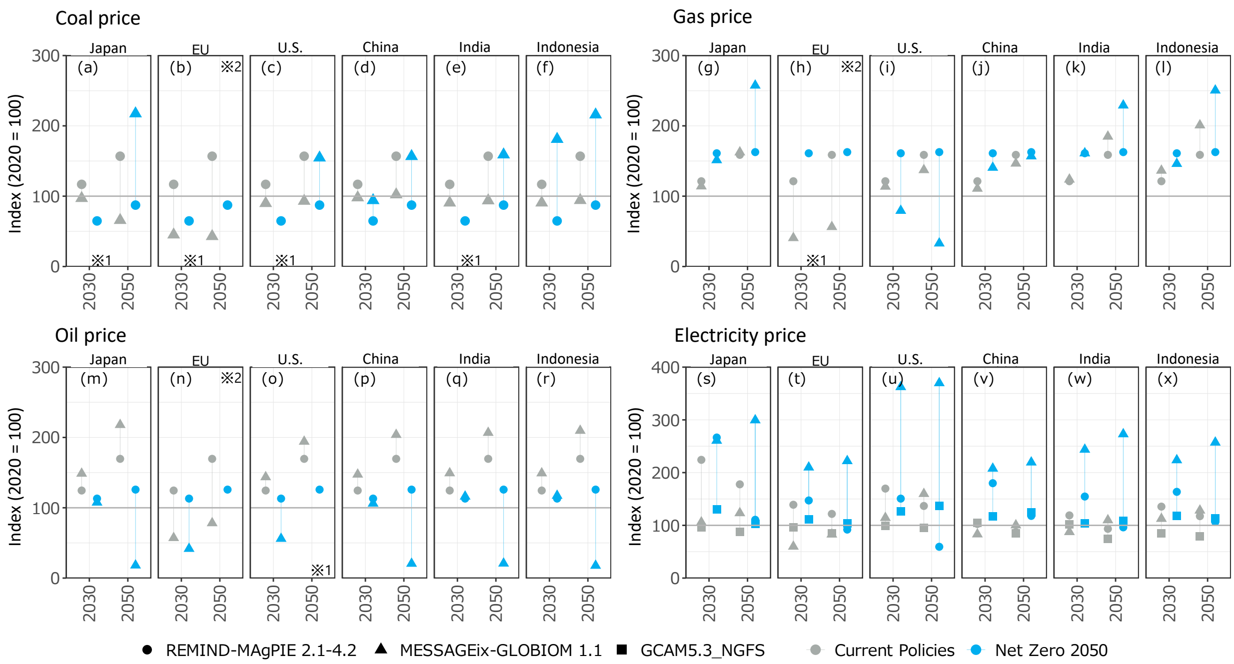
There are significant differences between the IAMs in terms of energy prices in 2030 and 2050.

Differences between the IAMs

REMIND-MAgPIE 2.1-4.2: There are few regional differences in terms of prices of fossil fuels (coal, gas and oil) (Figure 4.3.8(a)-®●). In Net Zero 2050, the electricity price will rise towards 2030 and then return to the 2020 level by 2050 in many regions (Figure 4.3.8(s)-(x)●), with the margin of increase in Japan expected to be the largest (Figure 4.3.8(s)●●).

MESSAGEix-GLOBIOM 1.1: Prices of fossil fuels (coal, gas and oil) will show an extreme rise in some regions in Net Zero 2050 but will become negative (drop below the 2020 level) in other regions (Figure 4.3.8(®(r)▲). The electricity price will rise in Net Zero 2050 in all regions (Figure 4.3.8(s)-(x)▲).

GCAM 5.3: Prices of fossil fuels (coal, gas and oil) are not reported by region. Regarding the electricity price, year-to-year price fluctuations and regional differences will be small (Figure 4.3.8(s)-(x)■■).



*1 Under MESSAGEix-GLOBIOM, energy prices will become negative in some regions in Net Zero 2050, but the negative prices are considered to be errors (the coal price in 2030 [Japan, the EU, the United States and India], the gas price in 2030 [the EU] and the oil price in 2050 [the United States]).

*2 Under MESSAGEix-GLOBIOM, fossil fuel prices in 2050 will rise extremely in EU in Net Zero 2050 (Coal: 632[US$2010/GJ], gas: 346[US$2010/GJ], and oil: 488[US$2010/GJ]).

Figure 4.3.8 Energy prices in major regions

4.3.9 Energy Investment (cumulative total until 2050)

In line with the worldwide trend, the value of energy investment is higher in scenarios with an ambitious greenhouse gas emission reduction policy (Net Zero 2050) in all regions. However, regarding electricity transmission and distribution, a certain amount of investment will be made in all scenarios. Moreover, there are significant differences between the IAMs in terms of the value of energy investment by region (Figure 4.3.9).

Characteristics of the regions

Japan, the EU and the United States (advanced economies): In all scenarios, the value of investment in fossil fuel electricity generation will remain small.

China, India and Indonesia (emerging economies): As in advanced economies, the value of investment in solar PV and wind power generation is higher in scenarios with an ambitious emission reduction policy. However, the rate of increase in the value of investment in Net Zero 2050 compared with Current Policies is higher in emerging economies than in advanced economies.

Differences between the IAMs

REMIND-MAgPIE 2.1-4.2: In line with the worldwide trend, the value of investment in wind power generation and energy storage will be large.

MESSAGEix-GLOBIOM 1.1: In Net Zero 2050, the value of investment in nuclear power will increase.

GCAM 5.3: The value of investment in wind power generation and energy storage will be the smallest of the three IAMs. On a worldwide basis, the value of investment in fossil fuel will be conspicuously higher than under the other two IAMs. However, on a region-by-region basis, the value of investment in fossil fuel will not necessarily be conspicuously higher than under the other two IAMs in each of the six regions.

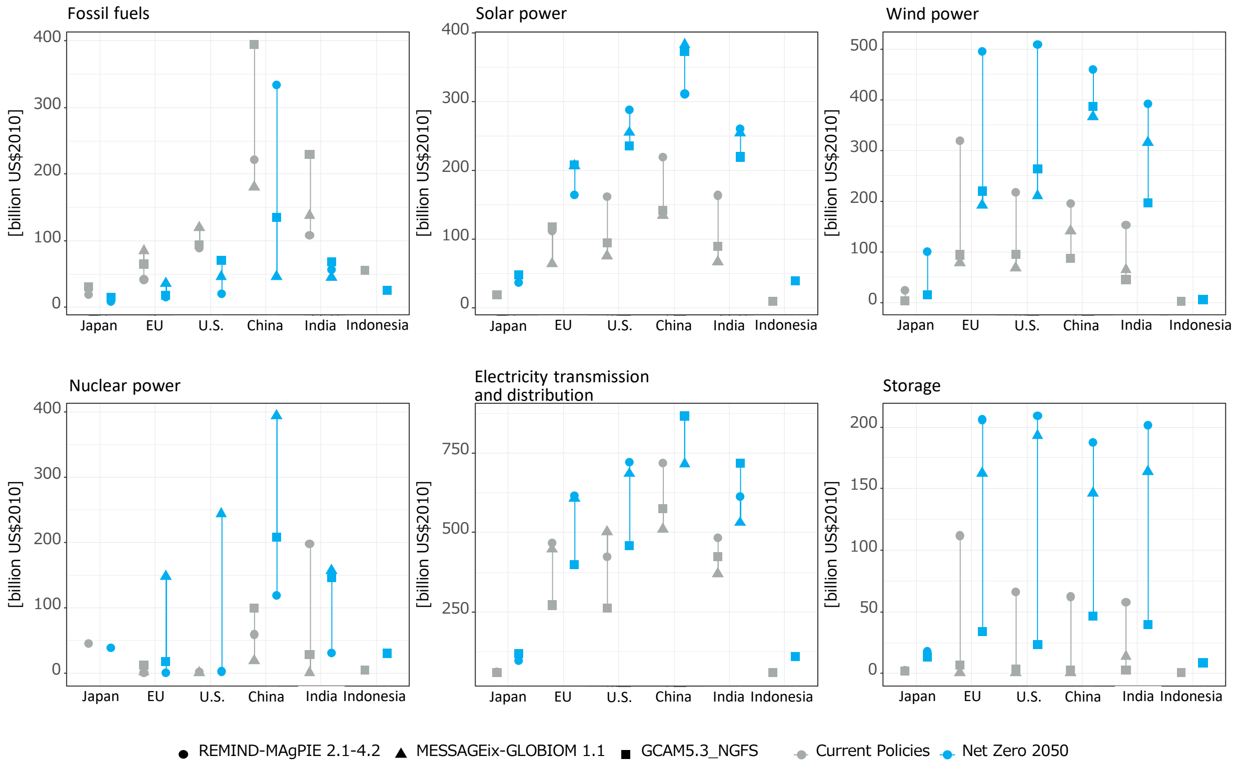


Figure 4.3.9 Cumulative energy-related investment in major regions

4.3.10 Summary: Inter-regional Comparison

A comparison regarding the variables of the NGFS Scenarios (Phase 2) between major regions around the world shows that even in the same scenario, the pace of introducing an emission reduction policy is different between advanced economies (Japan, the EU and the United States) and emerging economies (China, India and Indonesia) (Figure 4.3.3). According to an inter-regional comparison of carbon prices, in all scenarios, the carbon price will be higher in advanced economies (Japan, the EU and the United States) than in emerging economies (Chima, India and Indonesia). In addtion, carbon prices may vary widely among the advanced economies depending on the IAM. Specifically, under MESSAGEix-GLOBIOM 1.1, the carbon price in the EU will be outstandingly high in 2050, whereas the price in Japan will be low.

The regional differences in carbon price are also reflected in CO_2 emission volume. In scenarios that assume introduction of ambitious emission reduction policies (e.g., Net Zero 2050), emissions in 2050 will be negative in all advanced economies (Japan, the EU and the United States), while there will be small volumes of residual emissions in emerging countries (China, India and Indonesia) (Figures 4.3.1 and 4.3.2). This difference is presumed to be attributable to regional differences in the CO_2 removal technology capacity introduced. In advanecd economies (Japan, the EU and the United States), some volume of CO_2 removal technology capacity, mainly BECCS capacity, will be deployed by 2050, but in emerging economies (China, India and Indonesia), the capacitiy of such technology deployment will be limited (Figure 4.3.4).

On the other hand, regarding energy, which is the main source of CO_2 emissions, there are not conspicuous regional differences. In all regions, in scenarios ambitious emission reduction policies, the share of fossil fuels in primary energy and secondary energy (electricity) will decline towards 2050, while the share of non-fossil energy, mainly renewable energy, will increase (Figures 4.3.5 and 4.3.6). Moreover, in line with the worldwide trend, overall final energy volume will decline and the share of electricity will increase in all regions (Figure 4.3.7).

There are larger differences between the IAMs than between the regions or between scenarios in terms of the type of energy consumed and the share of investment by type of technology (Figure 4.3.9).

4.4 Comparison with Existing Scenarios (Worldwide and Japan)

The NGFS Scenarios (Phase 2) take into consideration future uncertainties by quantifying each of the six scenarios under three different IAMs. On the other hand, in the context of climate change mitigation, because of the abundance of scenario analyses so far accumulated, it is possible to identify a broader range of uncertainties using existing scenarios. Compared with the existing scenarios, the NGFS Scenarios (Phase 2) are limited in terms of the numbers of scenarios and IAMs, and as a result, a sufficiently broad range of uncertainties may not have been taken into consideration. Therefore, this section compares the scenario analysis results regarding the world and Japan. Based on this comparison, it is possible to identify the positions of the NGFS scenarios relative to the ranges of the variables of the existing scenarios and verify the sufficiency and validity of the NGFS Scenarios (Phase 2) by looking at the unevenness of the distribution of values of individual variables and relative size of the breadth of the range of uncertainties.

Regarding the world, the comparison is conducted with the scenarios of the Intergovernmental Panel on Climate Change's Special Report on Global Warming of 1.5C° (SR15; IPCC (2018)) and the scenarios of the World Energy Outlook 2021 of the International Energy Agency (WEO-2021; IEA (2021b)). With respect to Japan, the comparison is conducted with the Japan Model Intercomparison Project on Long-term Climate Policy (JMIP; Sugiyama et al. (2021a)) and the WEO-2021.

4.4.1 Notes on comparison

It should be kept in mind that when the comparison with the existing scenarios is conducted, the propositions and/or assumptions of the scenarios may not be strictly aligned. Strict comparison is impossible because the existing scenarios compared have been developed for different purposes. Although the propositions and assumptions have been aligned as much as possible by comparing scenarios similar to each other in terms of CO_2 emission trajectories and the level of temperature rise, some of those cannot be aligned.

Even when there are divergences from the compared scenarios, that does not mean that the validity of the NGFS scenarios is low. As scenarios are not forecasts, the comparison is not intended to determine which are superior to others among the scenarios. The comparison in this section is intended to identify the range of uncertainties in scenarios with similar levels of CO_2 emission trajectories and temperature rises.

4.4.2 Overview of the Compared Scenarios

Scenario database of the IPCC Special Report on Global Warming of 1.5ºC (SR15)

In a decision at the 21st Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP 21) in December 2015, the IPCC was invited "to provide by 2018 a Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways." In response, the IPCC published the IPCC Special Report on Global Warming of 1.5ºC in October 2018 (IPCC, 2018). The IPCC itself does not conduct scenario analysis but compiles academic literature with scenario data submitted by research institutions around the world. A total of 411 sets of scenario data submitted by 10 research institutions were used for compiling SR15 and were disclosed to the public.[12] With respect to each of those scenarios, the level of temperature rises in 2100 was calculated, and the scenarios were divided into six categories according to the level of temperature rise. In this section, we refer to the Below-1.5ºC, 1.5ºC-low-OS and1.5ºC-high-OS scenarios collectively as SR15 (1.5ºC), the Lower-2ºC and Higher-2ºC scenarios as SR15 (2ºC), and the Above-2ºC scenario as SR15 (Above 2ºC) (Table 4.4.1).

Table 4.4.1 Categories of scenarios in the IPCC SR15 [13]

Categories in this report	Categories in the IPCC SR15	Description	Number of scenarios
SR15 (1.5ºC)	Below-1.5ºC	The peak temperature rise during the 21st century will remain below 1.5ºC with a probability of 50-66%.	5
	1.5ºC-low-OS	The median temperature rise by 2100 will be below 1.5ºC, with the rise temporarily surpassing 1.5ºC during the 21st century with a probability of 50-67% (The difference from the peak temperature rise in Below-1.5ºC will be less than 0.1ºC or so. "OS" stands for overshooting).	37
Not used[14]	1.5ºC-high-OS	The median temperature rise by 2100 will be below 1.5ºC, with the rise temporarily surpassing 1.5ºC during the 21st century with a probability higher than 67% (The difference from the peak temperature rise in Below-1.5ºC will be less than 0.1-0.4ºC or so).	36
SR15 (2ºC)	Lower-2ºC	The peak temperature rise during the 21st century will remain below 2ºC with a probability higher than 66%.	54
	Higher-2ºC	The peak temperature rise during the 21st century will remain below 2ºC with a probability of 50-66%.	54
SR15 (Above 2ºC)	Above-2ºC	Other (The peak temperature rise during the 21st century will be above 2ºC with a probability higher than 50%)	124

JAMSTEC Model Intercomparison Project (JMIP)

JMIP is a model intercomparison project that evaluates Japan's long-term climate policy based on five IAMs (AIM/Enduse-Japan V2.1 (Oshiro and Masui, 2015), AIM/Hub-Japan 2.1 (Fujimori et al., 2017), DNE21 Version 1.3 (Fujii and Komiyama, 2015), IEEJ Japan ver.2017 (Matsuo et al., 2013), and TIMES-Japan 3.1 (Kato and Kurosawa, 2019)) developed and maintained by various research institution in Japan (University of Tokyo, Kyoto University, National Institute for Environmental Studies, Institute of Energy Economics, Japan, and Institute of Applied Energy). The project was implemented from 2017 to 2020.[15] Analysis was conducted mainly with respect to a scenario that assumed emission reductions of 26% in 2030 and 80% in 2050, which represented Japan's medium- and long-term goals at that time, and also with respect to scenarios that assumed reductions of 70%, 90% and 100% by 2050 were also analyzed as

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[12] IPCC SR1.5 Scenario Database (https://data.ene.iiasa.ac.at/iamc-1.5c-explorer)
[13] Of the 411 sets of scenario data submitted, a total of 13 sets of data, including those which deviate from the actual results in terms of GHG emission volume in 2010 and overlapping scenarios, were excluded from Table 2.4 in the main text of the IPCC Special Report on Global Warming of 1.5Cº (SR15), so such data sets were excluded from this paper as well. The number of scenarios analyzed came to 310.
[14] Although the level of temperature rise in 2100 in 1.5°C-high-OS is also 1.5°C, this scenario was excluded from the comparison because the emission pathways to 2050 deviate significantly from those in Net Zero 2050 and Divergent Net Zero among the NGFS scenarios.
[15] The project has now been renamed as the Japan Model Intercomparison Platform (JMIP) for Sustainable Futures (https://ifi.u-tokyo.ac.jp/en/units/jmip/), and its role as a credible and transparent forum that encourages discussions on model-based scenarios and related analysis has expanded. As for scenario analysis, comparative analysis concerning net zero emissions is ongoing.

part of a sensitivity analysis (with respect to the scenario that assumed reductions of 26% by 2030 and 80% by 2050 [26by30+80by50_Def], sensitivity analysis concerning the cost and potential of renewable energy, usability of nuclear power and CCS, the level of service demand, and import prices of energy was also conducted). The results of the analysis were summarized and published in a special feature issue of the journal Sustainability Science (Energy Scenarios for Long-Term Climate Change Mitigation in Japan) in the form of a peer-reviewed academic paper. The scenario data (JU, 2021) was also disclosed to the public (Sugiyama et al 2021a,b).

In this paper, scenarios related to emission reduction shown in Table 4.4.2 are used for comparison. In scenarios that assume more intense emission reduction policies, the number of scenarios that can be used as a reference is smaller because several iterations were unsolvable.

Table 4.4.2 Scenarios included in JMIP (excerpt)

Categories in this report	Categories in JMIP	Description	Number of scenarios	IAM
JMIP (Net Zero)	26by30+100by50_Def	NDC (26% reduction by 2030), and 100% reduction by 2050	2	AIM/Hub-Japan 2.1 DNE21 Version 1.3
JMIP (90% reduction)	26by30+90by50_Def	NDC (26% reduction by 2030), and 90% reduction by 2050	3	AIM/Enduse-Japan V2.1 AIM/Hub-Japan 2.1 DNE21 Version 1.3
JMIP (80% reduction)	26by30+80by50_Def	NDC (26% reduction by 2030), and achievement of a long-term goal (80% reduction by 2050)	5	AIM/Enduse-Japan V2.1 AIM/Hub-Japan 2.1 DNE21 Version 1.3 IEEJ Japan ver.2017 TIMES-Japan 3.1
JMIP (70% reduction)	26by30+70by50_Def	NDC (26% reduction by 2030) and 70% reduction by 2050	5	
JMIP (Baseline)	Baseline_Def	Assumption of absence of a climate policy (setting of a default variable value)	5	

<u>IEA World Energy Outlook (WEO-2021)</u>

The WEO-2021 is the 2021 edition of the IEA's annual report that provides an analysis of the outlook on the global energy situation (IEA, 2021b). In addition to analyzing the recent energy situation, the WEO conducts a scenario analysis concerning the outlook on energy in the period until 2050. The WEO-2021 presented three scenarios, i.e., the Stated Policy Scenario (STEPS), the Announced Pledge Scenario (APS) and the Net Zero Emissions by 2050 Scenario (NZE). While the main text of the WEO-2021 mainly describes the results of scenario analysis for the world, separate data on country-by-country results, including the results for Japan, are publicly available (some data is available upon charge). The level of temperature rise was calculated based on GHG emission volume in each scenario. The calculated temperature rise in 2100 is 2.6°C in STEPS, 2.1°C in APS and 1.4°C in NZE.

The scenarios presented in the WEO-2021 are calculated under a simulation model called the World Energy Model (IEA, 2021a).

Table 4.4.3 Scenarios included in the WEO-2021

Categories in this report	Categories in the WEO-2021	Description	Number of scenarios
WEO-2021 (NZE)	Net Zero Emissions by 2050 Scenario	The standard IEA scenario that shows a pathway for achieving net zero CO_2 emissions by 2050 in the energy sector on a worldwide basis	1
WEO-2021 (APS)	Announced Pledge Scenario	A scenario which assumes that climate change commitments made by governments around the world, including NDCs and net zero emission goals, will be implemented by the target deadlines.	1
WEO-202 (STEPS)	Stated Policy Scenario	A scenario which does not assume the implementation of all goals announced by governments as of now and which serves as a more conservative future benchmark.	1

4.4.3 Comparison with the NGFS Scenarios

With respect to the world and Japan, pairs of scenarios used for comparison have been selected based on the following criteria.

Regarding the world, scenarios for comparison have been selected based on the level of temperature rise in 2100 (Table 4.4.4). Among the NGFS scenarios, a temperature rise of 1.5°C is expected in Net Zero 2050 and Divergent Net Zero, so these two scenarios are compared with the 1.5°C Scenario of SR15 (SR15 [1.5°C]) and the NZE Scenario of the WEO-2021(WEO-2021 [NZE]). Among the NGFS scenarios, temperature rises of 1.7ºC and1.8ºC are expected in Below 2ºC and Delayed Transition, respectively, so these two scenarios are compared with scenarios in which a similar level of temperature rise is expected, i.e., the 2°C Scenario of SR15 (SR15 [2°C]) and APS of the WEO-2021 (WEO-2021 [APS]). In NDCs and Current Policies, a temperature rise of 2ºC or higher is expected, so these two scenarios are compared with the Above 2°C Scenario of SR15 (SR15 [Above 2°C]) and STEPS of the WEO-2021 (WEO-2021 [STEPS]).

Table 4.4.4 NGFS scenarios and the scenarios for comparison (worldwide)

NGFS scenarios		Scenarios for comparison		
Scenario	Temperature rise	Scenario	Temperature rise	Number of scenarios
Net Zero 2050	1.5°C	IPCC SR15 (1.5°C)	1.5°C	90
Divergent Net Zero	1.5°C	WEO-2021(NZE)	1.4°C	1
Below 2ºC	1.7ºC	IPCC SR15(2°C)	2°C	132
Delayed Transition	1.8°C	IEA WEO-2021(APS)	2.1°C	1
NDCs	2.5°C	SR15(Above 2°C)	>2°C	189
Current Policies	3.0°C	WEO-2021(STEPS)	2.6°C	1

Figure 4.4.1 shows CO_2 emission volumes for each pair of scenarios compared. In terms of emission volume in 2050, the volumes in the NGFS scenarios and the scenarios with which they are compared are similar to each other (in the case of SR15, although there are some disparities in emission volume because of the large number of scenarios, the volumes in the SR15 scenarios are similar to the ones in the NGFS scenarios in terms of the median value with respect to all pairs of scenarios compared). Therefore, it has been concluded that the selection of the pairs of scenarios for comparison is generally appropriate.

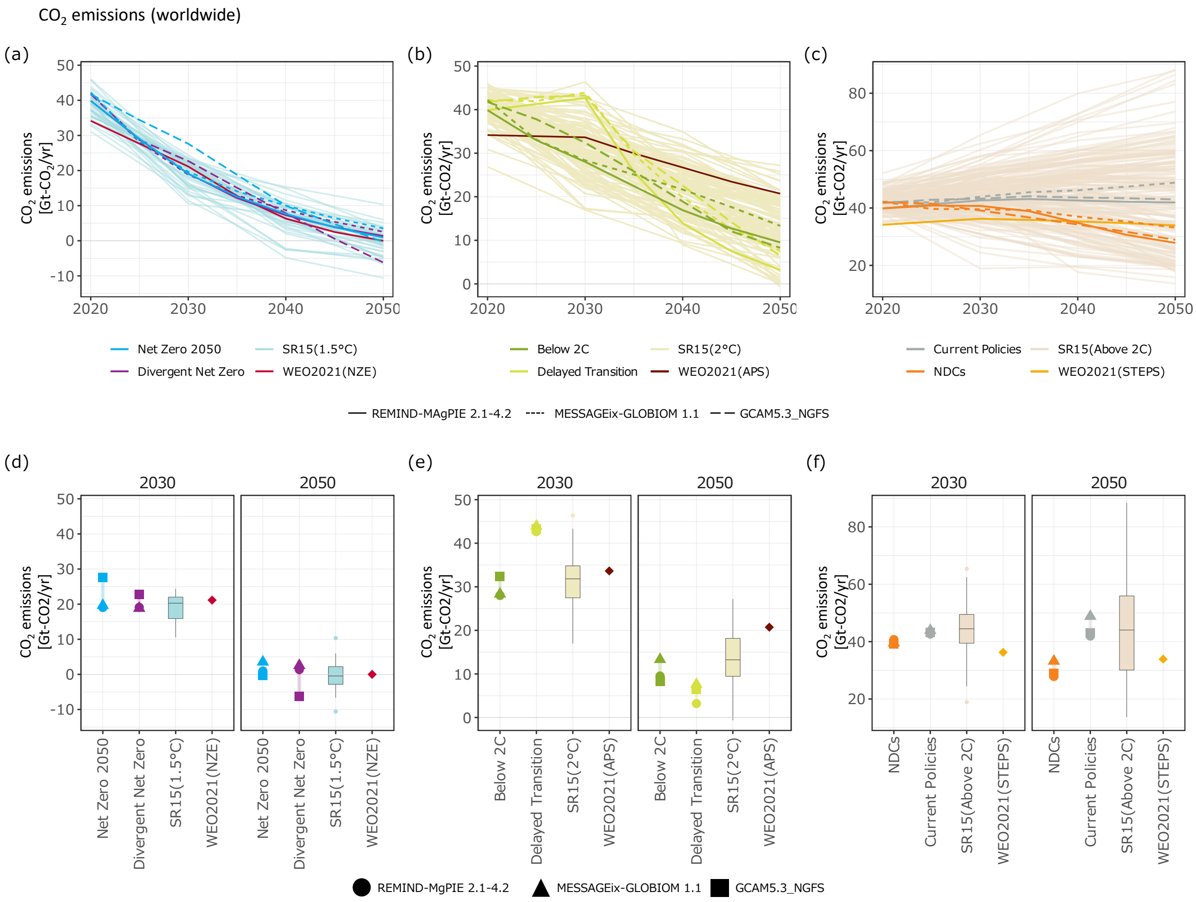

Figure 4.4.1 CO_2 emissions for each pair of scenarios compared (worldwide)

Regarding Japan, from among the JMIP and WEO-2021 scenarios, those similar to the NGFS scenarios in terms of CO_2 emission volume have been selected for comparison (Table 4.4.5).

It should be noted that while country-by-country CO_2 emission volume is determined through the optimization process implemented for the world, the method of determining CO_2 emission volume under the JMIP is different because emission constraints are imposed on Japan alone and a specific emission volume is designated for each scenario. As a result of this difference, whereas emissions will become negative under some IAMs in the NGFS scenarios where net zero emission is achieved, emission volume is fixed at zero under all IAMs in the JMIP (Net Zero) scenario.

Table 4.4.5 NGFS scenarios and the scenarios for comparison (Japan)

NGFS scenario		Scenarios for comparison		
Scenario	CO_2 emission volume (2050) [Mt-CO_2/yr]	Scenario	CO_2 emission volume (2050) [Mt-CO_2/yr]	Number of scenarios
Net Zero 2050	-104 to 61	JMIP (90% reduction)	128 to 182	3
Divergent Net Zero	-121 to 49	JMIP (Net Zero)	0 to 1.4	2
Delayed Transition	-62 to 102	WEO-2021 (APS)	2.0	1
Below 2ºC	133 to 296	JMIP (70% reduction)	364 to 515	5
		JMIP (80% reduction)	246 to 347	5
NDCs	267 to 638	JMIP (Baseline)	564 to 1648	5
Current Policies	593 to 954	WEO (STEPS)	513	1

Figure 4.4.2 shows CO_2 emission volumes for each pair of scenarios compared. Figure 4.4.2 confirms that the emission volumes for the compared scenarios are similar within each pair. Therefore, it has been concluded that the selection of the pairs of scenarios for comparison is generally appropriate.

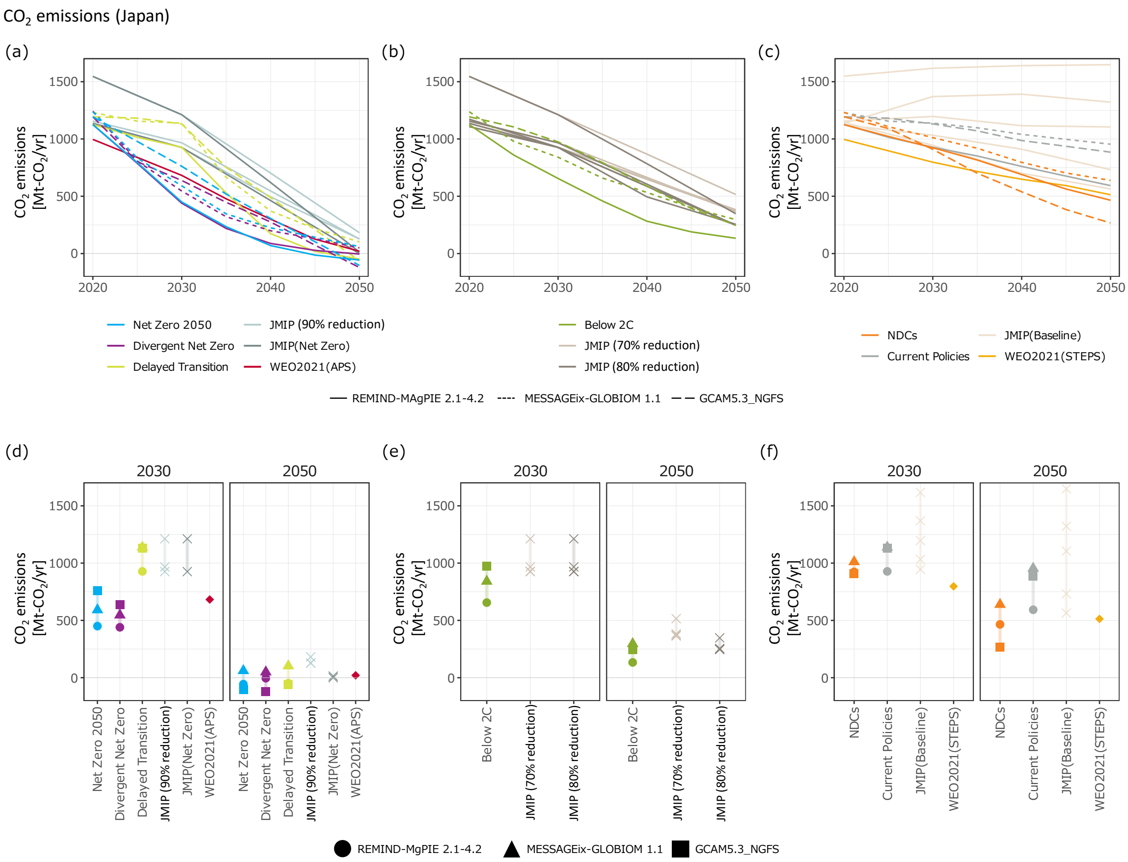

Figure 4.4.2 CO_2 emission volumes for each pair of scenarios compared (Japan)

4.4.4 Carbon Prices

Figures 4.4.3 (worldwide) and 4.4.4 (Japan) show the results of carbon price comparison. The upper row shows changes in the carbon price between 2020 and 2050 in each scenario. The lower row shows the carbon prices in 2030 and 2050 in each pair of scenarios compared. With respect to SR15, which includes a large number of scenarios, a box-and-whisker plot[16] is used to graphically show the distribution of values (the larger the box is and the longer the whisker is, the larger the variance of values across the scenarios is). Regarding the WEO-2021 scenarios, there are multiple plots for each scenario because those scenarios present carbon price assumptions on a region-by-region or country-by-country basis. Therefore, the results for the world are represented by the region-by-region or country-by-country results.[17] As for the

[16] A quarter of the total number of scenarios are included in each of the four ranges (from the upper end of the whisker to the upper end of the box, from the upper end of the box to the line within the box, from the line within the box to the lower end of the box, and from the lower end of the box to the lower end of the whisker). An outlier is defined as a data point that is outside 1.5 times the box range above the upper end and below the lower end of the box.

[17] In WEO-2021 (NZE), the regional categories are "Advanced economies," "Major emerging economies," and "Other

results for Japan, while WEO-2021 (APS) presents carbon price trajectory specifically for Japan, WEO-2021 (STEPS) does not present Japan-specific carbon price trajectory. Therefore, with respect to WEO-2021 (STEPS), the results for Japan are represented by the same region-by-region or country-by-country results as the ones indicated for the world.

Worldwide (Figure 4.4.3)

Within each of the NGFS scenarios, the carbon price level varies across the IAMs. On the other hand, regarding SR15, which includes a large number of scenarios, either the carbon price remains within the range of the variance observed in the NGFS scenarios, or its variance is larger than in the NGFS scenarios. In other words, it can be concluded that carbon prices in the NGFS scenarios are within the range of carbon prices observed in the scenarios of SR15 with which those scenarios are compared, and therefore carbon prices in the NGFS scenarios are not outliers.

Meanwhile, there are divergences in the carbon price between the WEO-2021 scenarios and the corresponding NGFS scenarios for comparison. Specifically, among the NGFS scenarios, the carbon prices in Net Zero 2050 and Divergent Net Zero, which assumes introduction of the most ambitious emission reduction policy, are higher than the price in the WEO-2021 (NZE. This difference is due to a difference in how carbon prices are calculated within models in each of the NGFS scenarios and the WEO-2021 scenarios. In the case of the NGFS scenarios, the carbon price is a "shadow price" calculated under each IAM, while in the case of the WEO-2021 (NZE), the carbon price is set as an exogenous variable (as a input value) which was determined at the level that triggers a change in energy demand by realigning the relative cost by type of fuel or at the level prescribed under a national policy.

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emerging market and developing economies." In WEO-2021 (APS), the regional categories are "Advanced economies with net zero pledges," "China," and "Emerging market and developing economies with net zero pledge." In WEO-2021 (STEPS), the categories are "Canada," "Chile," "Colombia," "China," "EU," and "Korea."

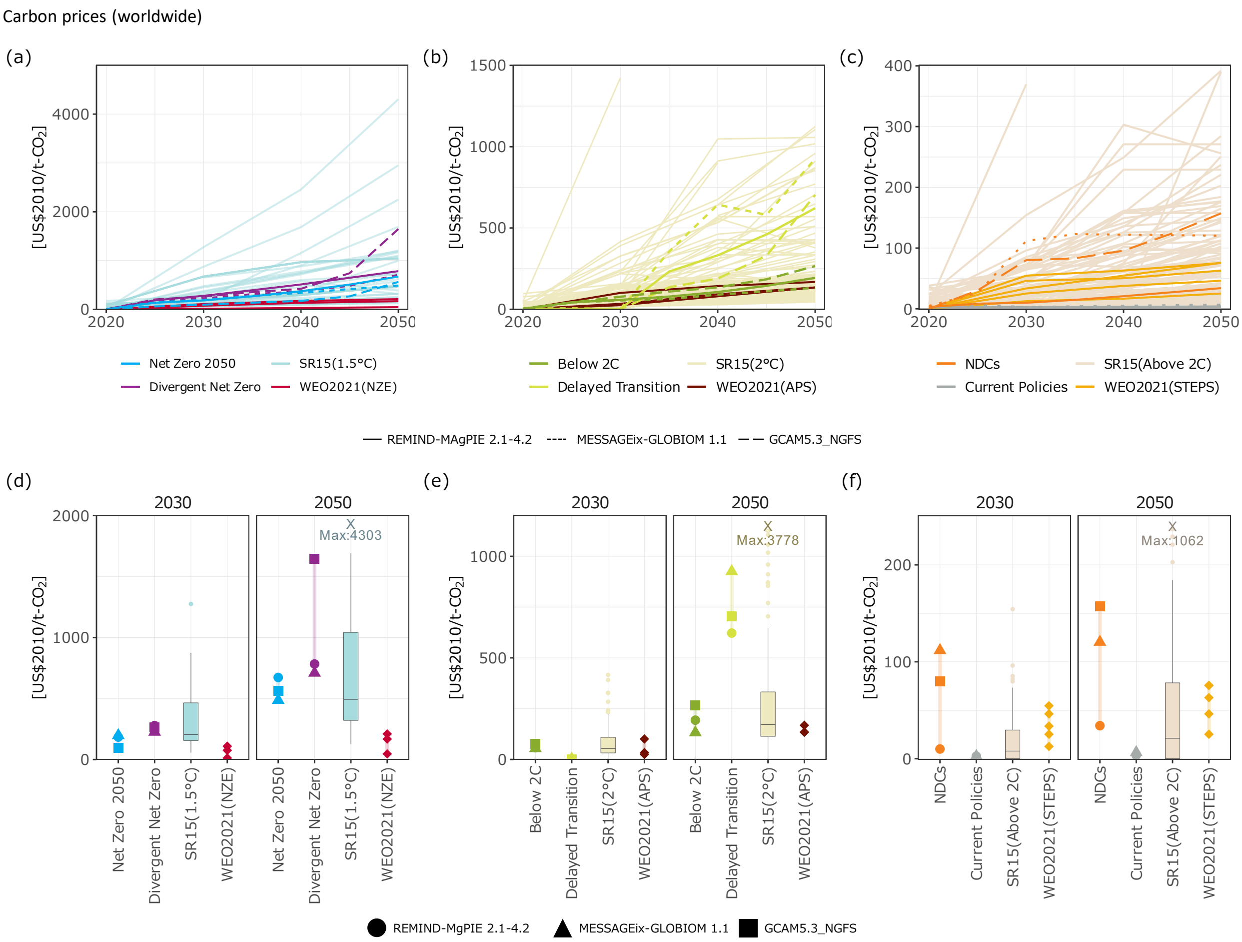

Figure 4.4.3 Carbon prices for each pair of scenarios compared (worldwide)

Japan (Figure 4.4.4)

In line with the worldwide trend, the carbon price varies across the IAMs within each of the NGFS scenarios, and the variance of the carbon price in the JMIP scenarios is similar to or larger than those observed in the NGFS scenarios. It should be noted that among the NGFS scenarios, the variance of the carbon price in NDCs in particular is larger than the variance observed in the JMIP scenario compared. This is presumably because national emission reduction policies became more ambitious at the time when the NGFS Scenarios (Phase 2) were developed (2021) than in the period when the JMIP was implemented (2017-2019).

As for the comparison with the IEA's WEO-2021, in line with the worldwide trend, the carbon prices in the NGFS scenarios that assume introduction of ambitious emission reduction policies (Net Zero 2050 and Divergent Net Zero) are higher than the prices in the WEO-02021 scenarios.

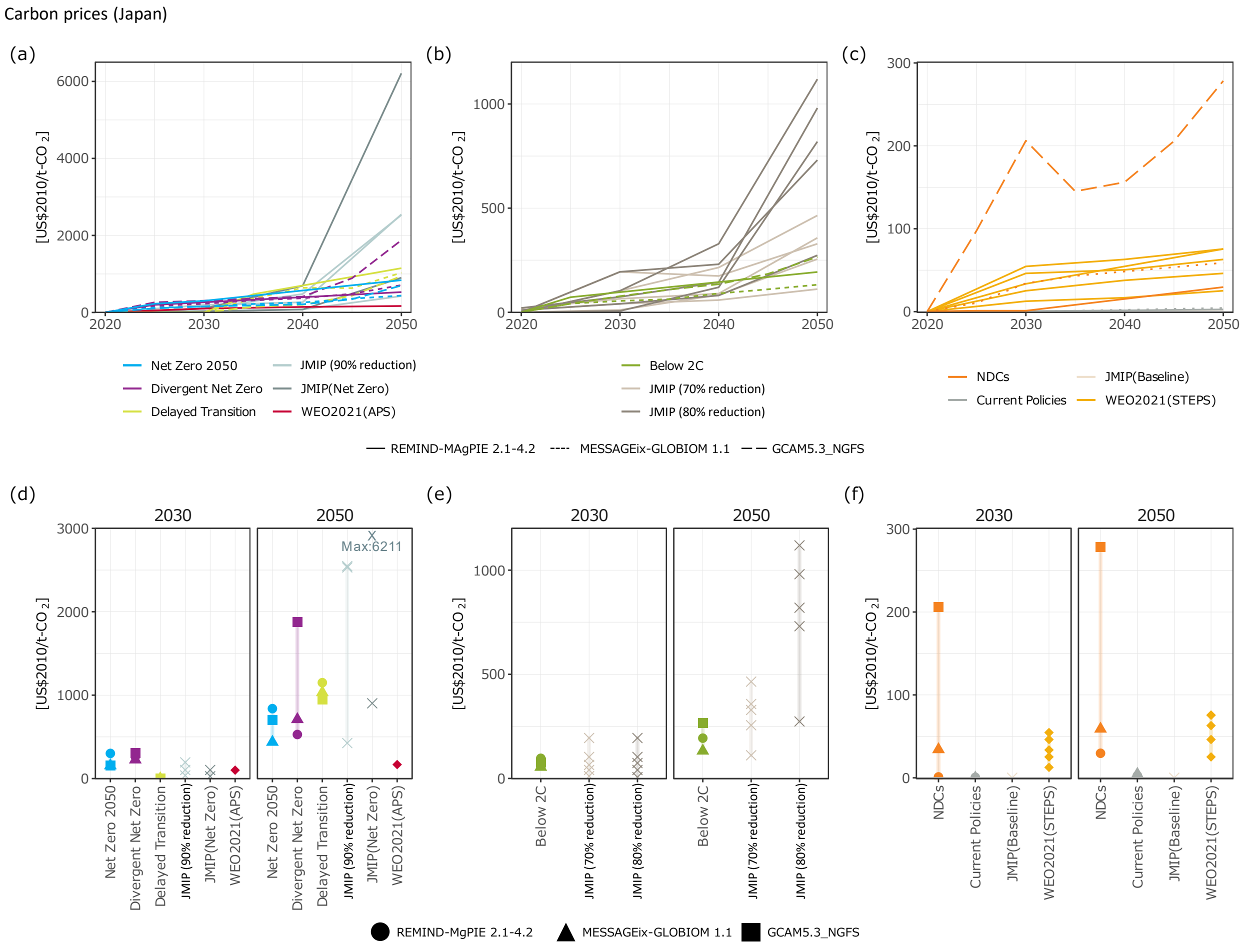

Figure 4.4.4 Carbon prices for each pair of scenarios compared (Japan)

4.4.5 CO_2 Emissions by Sector

Worldwide (Figure 4.4.5)

Figure 4.4.5 shows worldwide CO_2 emission volume by sector in 2050. The dots indicate the distribution of CO_2 emission volume in the NGFS scenarios and the WEO-2021 scenarios, while the box-and-whisker plots indicate the distribution of CO_2 emission volume in the SR15 scenarios. MESSAGEix-GLOBIOM 1.1 does not report CO_2 emission volume by sector in Japan.

CO_2 emission volumes in the NGFS scenarios are distributed mostly within the ranges of volumes in the SR15 and WEO-2021 scenarios in all sectors. For example, although CO_2 emission volume varies across the IAMs in the industrial sector in the NGFS scenarios (under GCAM, the volume of residual CO_2 emissions in the industrial sector when net zero emission has been achieved will be larger than under the other two IAMs), the variance is within the range of CO_2 emission volumes in the industrial sector in the SR15 scenarios.

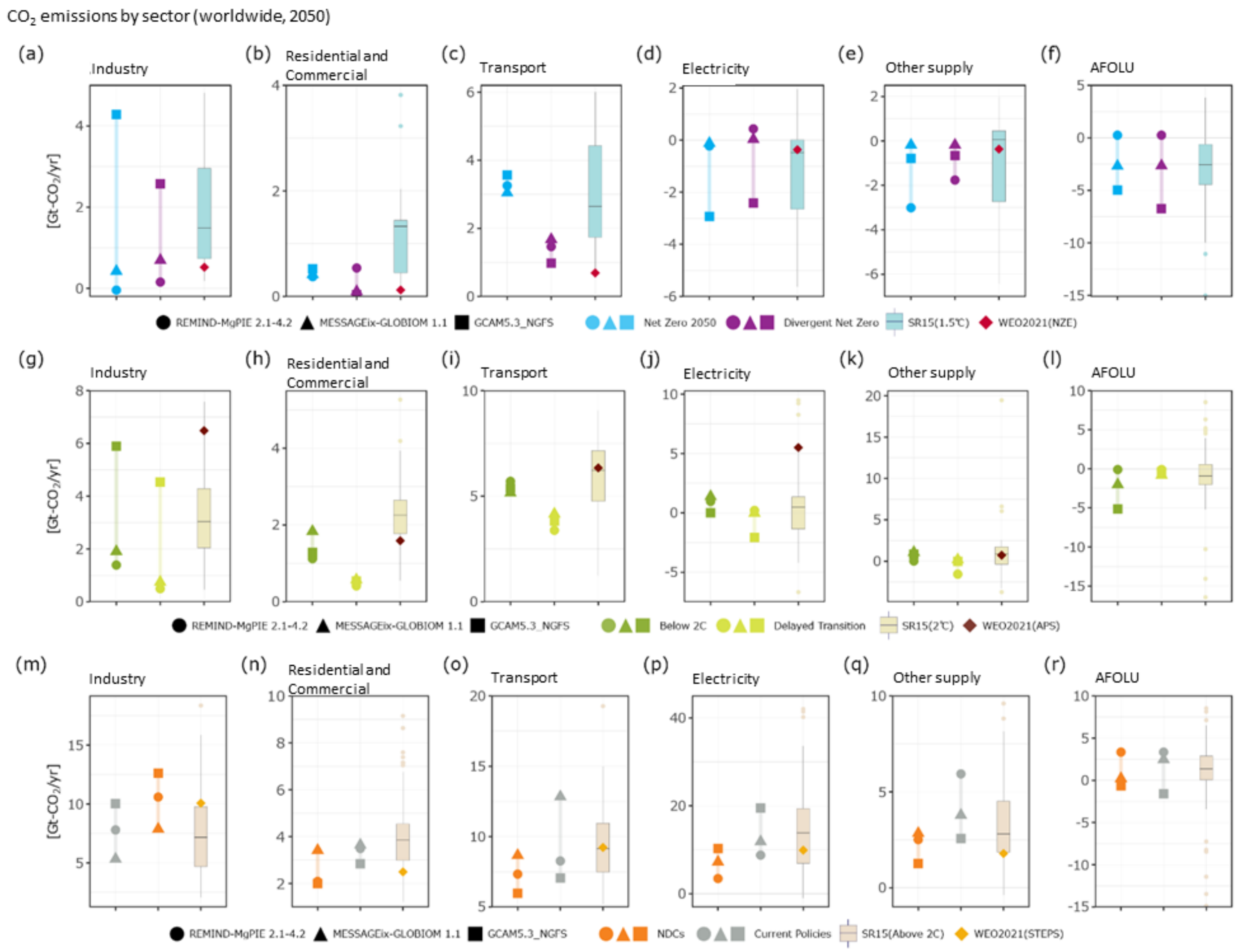

Figure 4.4.5 CO_2 emission volumes by sector for each pair of scenarios compared (2050, worldwide)

Japan (Figure 4.4.6)

Net Zero 2050 (1.5ºC) and Divergent Net Zero (1.5ºC): In line with the worldwide trend, CO_2 emission volumes in the NGFS scenarios are distributed mostly within the ranges of emission volumes in the JMIP and WEO-2021 scenarios in all sectors. However, while emission volume in the industrial sector (Figure 4.4.6(a)) will become negative in some NGFS scenarios, that does not occur in any of the JMIP or WEO-2021 scenarios. Meanwhile, emission volume in the residential and commercial sector (Figure 4.4.6(b)) will fall to almost zero in the NGFS scenarios, so CO_2 emission volumes in those scenarios are concentrated around the bottom of the distribution ranges of emission volumes in the JMIP and WEO-2021 scenarios.

NDCs (2.5ºC): Although emission volume in the industrial sector in NDCs is at a level lower than the ranges of emission volumes in the JMIP and WEO-2021 scenarios (Figure 4.4.6(m)), emission volumes in other scenarios are within those ranges.

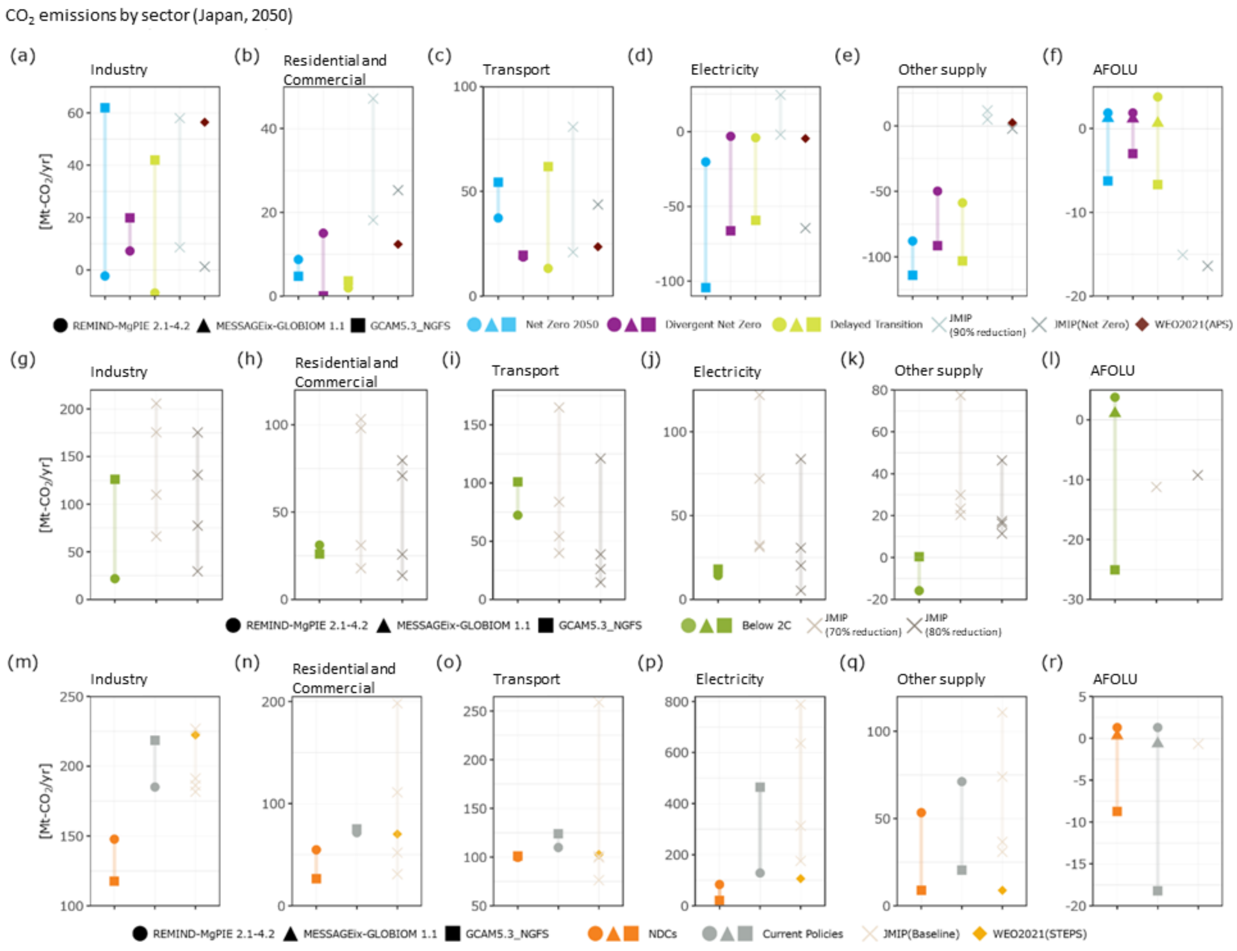

Figure 4.4.6 CO_2 emission volumes by sector for each pair of scenarios compared (2050, Japan)

4.4.6 CO_2 Removals

<u>Worldwide (Figure 4.4.7)</u>

Net Zero 2050 (1.5ºC) and Divergent Net Zero (1.5ºC): CO_2 removal volumes under all IAMs in all NGFS scenarios are distributed within the range of the distribution in the SR15 scenarios, which means that the level of CO_2 removal volume does not depend extremely on CO_2 emission volume.

Below 2ºC (1.7ºC) and Delayed Transition (1.8ºC): While CO_2 removal volumes in the NGFS scenarios are mostly distributed within the range of volumes in the SR15 scenarios, there are some distinctive trends. For example, regarding BECCS (liquids), the CO_2 removal volumes under MESSAGEix-GLOBIOM 1.1 and GCAM 5.3 are located near the lowest level of volume in the SR15 (2ºC) scenario. Regarding afforestation, under REMIND-MAgPIE 2.1-4.2, the capacity introduced is lower than the range of capacity in SR15 (2ºC).

NDCs (2.5ºC) and Current Policies (3ºC+): Regarding BECCS (electricity) and BECCS (hydrogen), under GCAM, the volume is larger than the range of capacity in SR15 (Above 2ºC). Regarding afforestation, under REMIND-MAgPIE 2.1-4.2, the volume is smaller than the range of capacity in SR15 (Above 2ºC).

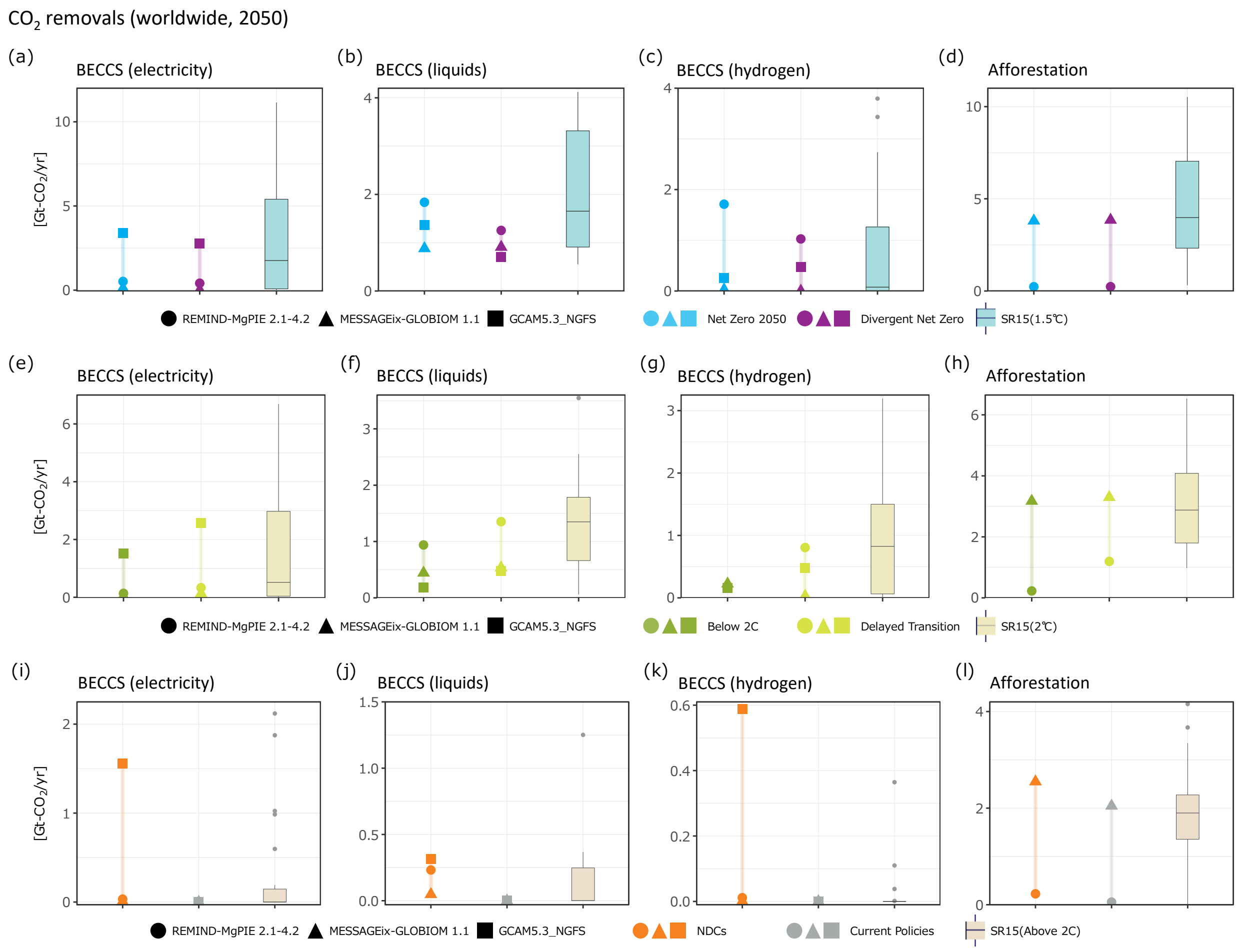

Figure 4.4.7 CO_2 removal volumes for each pair of scenarios compared (2050, Worldwide)

Japan (Figure 4.4.8)

Net Zero 2050 (1.5ºC), Divergent Net Zero (1.5ºC), and Delayed Transition (1.8ºC): Volumes of CO_2 removal due to BECCS (electricity) in the NGFS scenarios are distributed within the range of volumes in the JMIP scenarios. On the other hand, the JMIP scenarios do not assume deployment of CO_2 removal due to BECCS (hydrogen), and the capacity of BECCS (liquids) introduced in those scenarios is small. It may be said that one distinctive characteristic of the NGFS scenarios for Japan is the assumption of deployment of CO_2 removal technology in sectors other than electricity.

With respect to the JMIP scenarios compared in which emission volume in Japan in 2050 will fall by 90% and by 100%, respectively, a solution has not been obtained under some IAMs. One possible reason is that existing scenarios for Japan have not given consideration to deployment of CO_2 removal technology in sectors other than electricity as a precondition (Shiraki et al., 2021).

Below 2ºC (1.7ºC): Volumes of CO_2 removal due to BECCS (electricity) in the NGFS scenario are distributed within the range of volumes in the JMIP scenarios. On the other hand, the JMIP scenarios do no assume introduction of BECCS (hydrogen), and the capacity of BECCS (liquids) introduced in those scenarios is small. It may be said that one distinctive characteristic of the NGFS scenario for Japan is the assumption of deployment of CO_2 removal technology in sectors other than electricity.

NDCs (2.5ºC) and Current Policies (3ºC+): Of these two NGFS scenarios, NDCs assumes deployment of CO_2 removal technology, but none of the JMIP scenarios do.

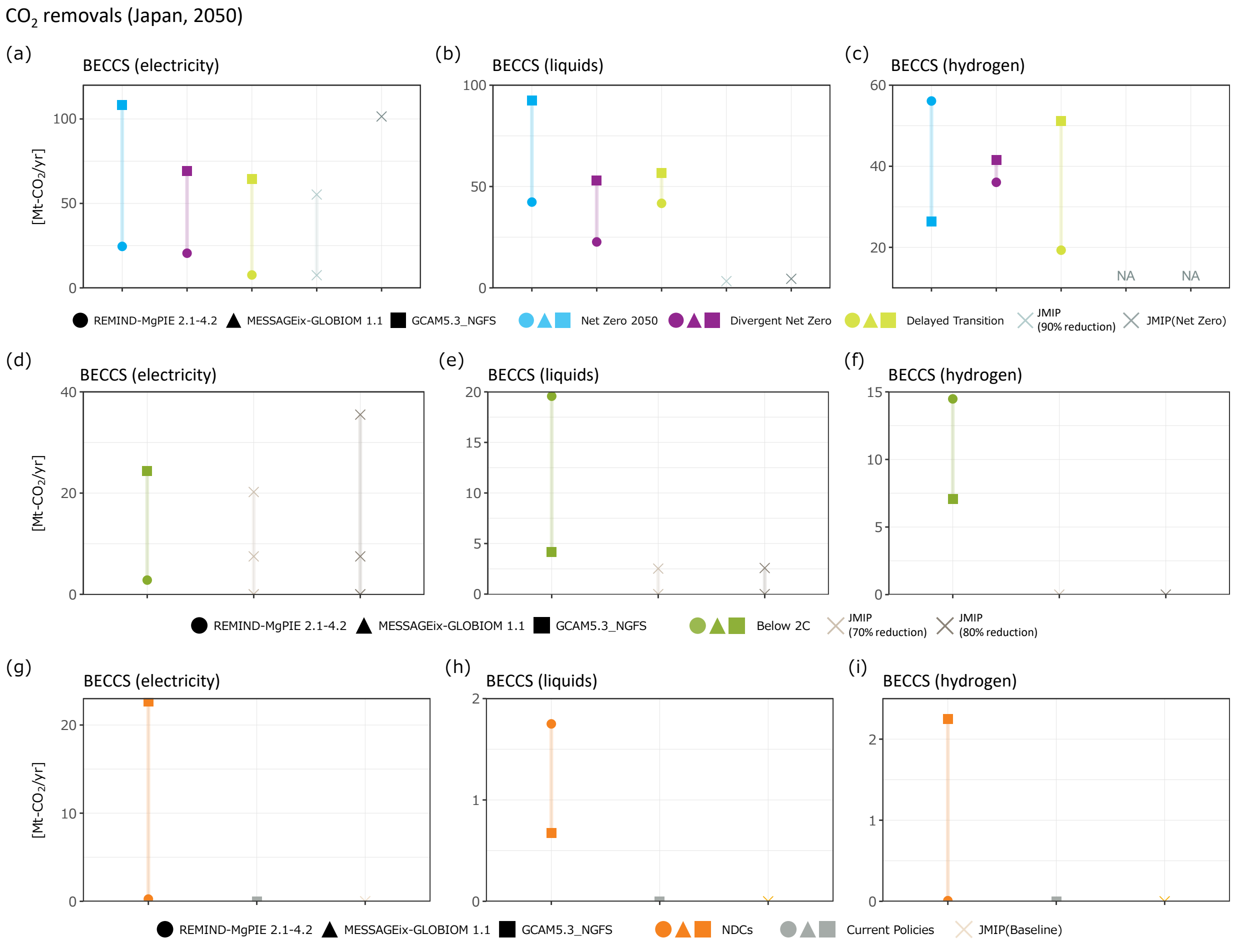

Figure 4.4.8 CO_2 removal volumes for each pair of scenarios compared (2050, Japan)

4.4.7 Energy Prices (Rate of Change Compared with 2020)

<u>**Worldwide (Figure 4.4.9)**</u>

Net Zero 2050 (1.5°C) and Divergent Net Zero (1.5°C): The rates of change in energy prices in the NGFS scenarios are mostly distributed within the ranges of rates of change in the SR15 scenarios. However, regarding the coal price, the rate of change in Divergent Net Zero is lower than in the SR15 scenario compared.

Below 2°C (1.7°C) and Delayed Transition (1.8°C): The rates of change in energy prices in the NGFS scenarios are mostly distributed within the ranges of rates of change in the SR15 scenarios. However, regarding some energy prices, such as the gas price, the rates of change are not entirely distributed within the ranges of rates of change in the SR15 scenarios.

NDCs (2.5°C) and Current Policies (3°C+): While the rates of changes in energy prices in the NGFS scenarios are mostly distributed within the ranges of rates of change in the SR15 scenarios, the variance in the NGFS scenarios is smaller.

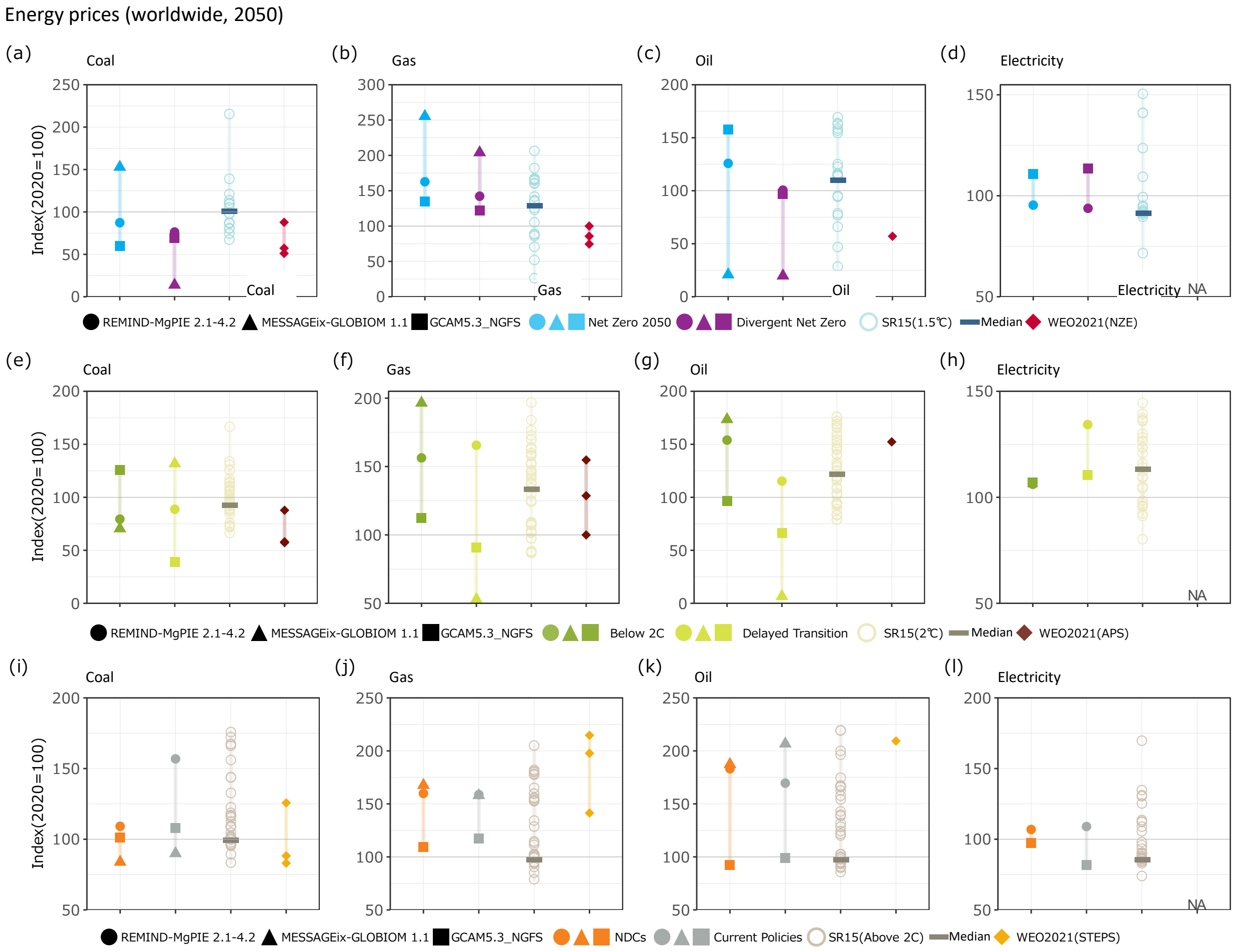

Figure 4.4.9 Energy prices for each pair of scenarios compared (2050, Worldwide)[18]

Japan (Figure 4.4.10)

Net Zero 2050 (1.5ºC), Divergent Net Zero (1.5ºC), and Delayed Transition (1.8ºC): There are some differences between the NGFS scenarios and the JMIP and WEO-2021 scenarios. Regarding all of coal, gas and oil, the rate of change (decrease) under MESSAGEix-GLOBIOM 1.1 is conspicuously higher or lower than the rates of change in the JMIP and WEO-2021 scenarios. This may reflect the effects of energy prices not having been downscaled (see Section 4.2.9). On the other hand, the rate of change under REMIND-MAgPIE 2.1-4.2 is close to the rates of change in the JMIP and WEO-2021 scenarios. The rates of increase in the electricity price in the JMIP scenarios are at a level around the middle of the ranges of rates of change in the NGFS scenarios.

Below 2ºC (1.7ºC): Regarding coal, gas and electricity, the rate of change (decrease) under MESSAGEix-GLOBIOM 1.1 in the NGFS scenario deviates significantly from the rates of change in the JMIP scenarios, while the rates of change under REMIND-MAgPIE 2.1-4.2 and GCAM.3 (only electricity) are relatively close to the rates of change in the JMIP and WEO-2021 scenarios. With respect to oil, the range of rates of change in the JMIP scenarios is large, while the range of rates of change in the NGFS scenarios is small.

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[18] In the WEO-2021, coal and gas prices are reported on a country-by-country basis, so the United States, the EU, and China were selected for comparison.

NDCs (2.5ºC) and Current Policies (3ºC+): Regarding gas, the rate of price increase in the NGFS scenarios is higher than the rates of increase in the JMIP and WEO-2021 scenarios. With respect to coal and electricity, while the range of rates of change in the NGFS scenarios is larger, but regarding oil, the range of rates of change in the JMIP and WEO-2021 scenarios is larger.

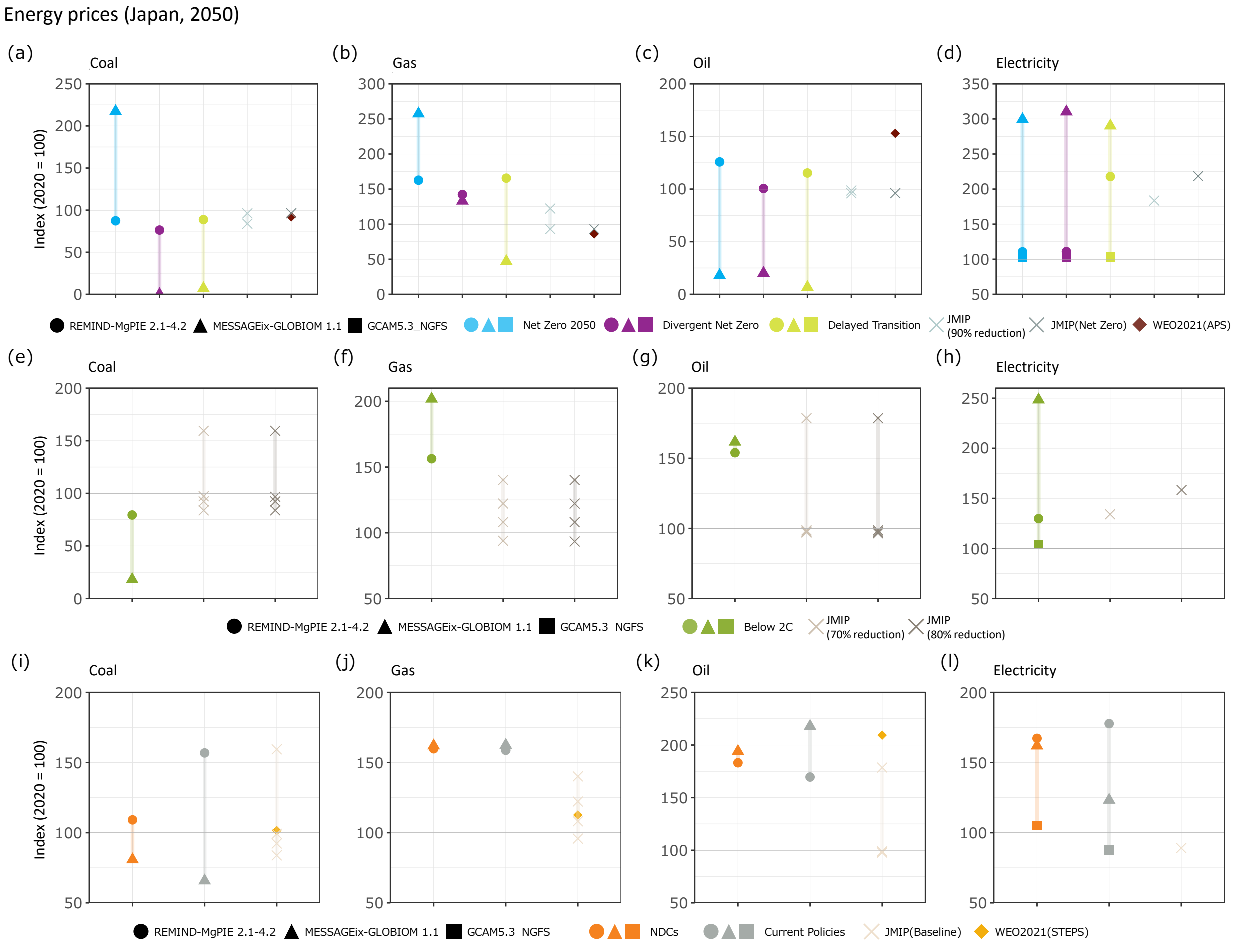

Figure 4.4.10 Energy prices for each pair of scenarios compared (2050, Japan)[19]

[19] In the WEO-2021, only the worldwide oil price is reported, so the comparison was conducted with the worldwide price.

4.4.8 Energy (Primary Energy, Electricity Generation, and Final Energy)

Energy in the NGFS scenarios for the world (Figure 4.4.11) are distributed within the ranges of volumes in the SR15 and WEO-2021 scenarios, and energy in the NGFS scenarios for Japan (Figures 4.4.12) are distributed within the ranges of volumes in the JMIP and WEO-2021 scenarios.

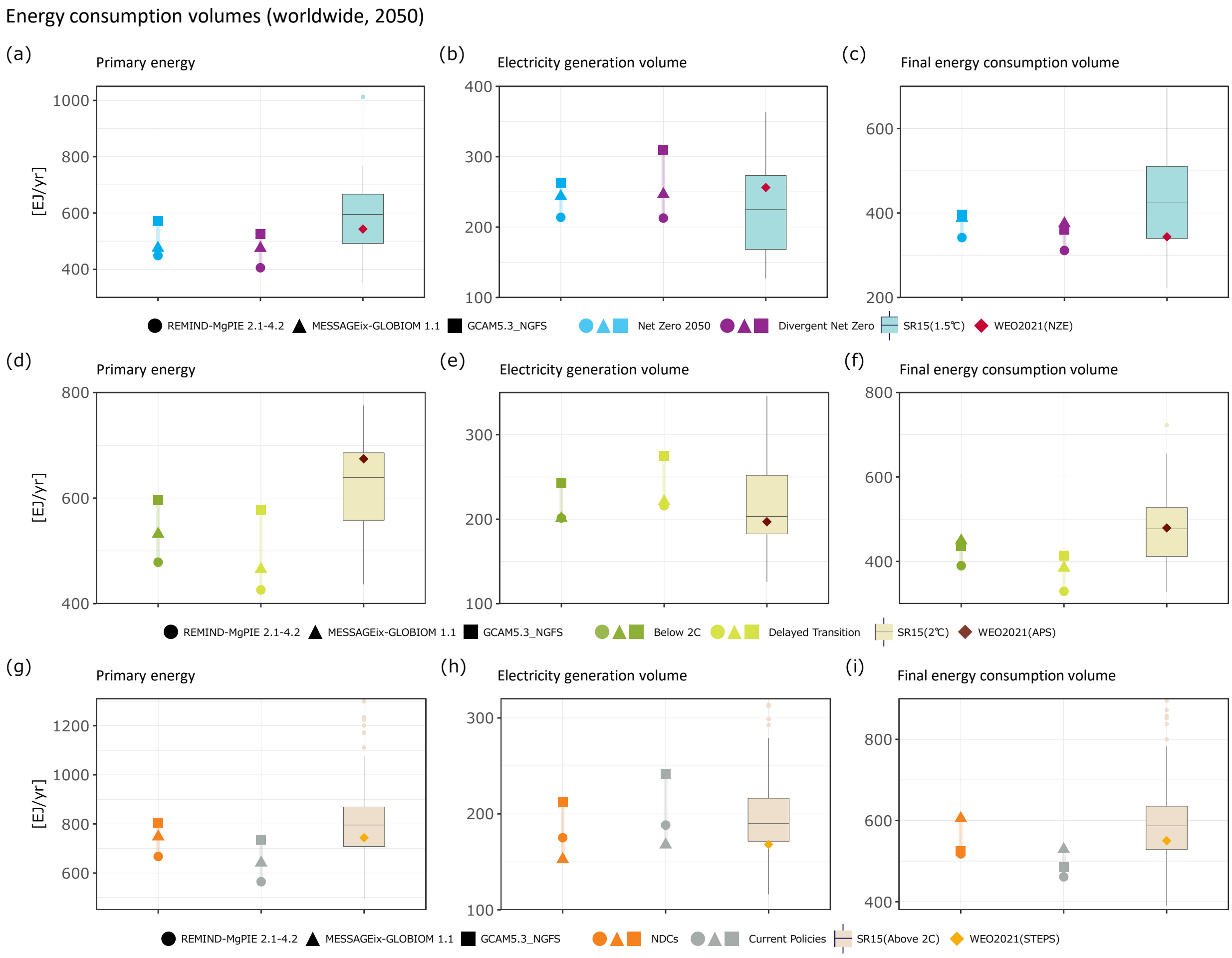

Figure 4.4.11 Energy (primary energy, electricity generation volume, and final energy) for each pair of scenarios compared (2050, Worldwide)

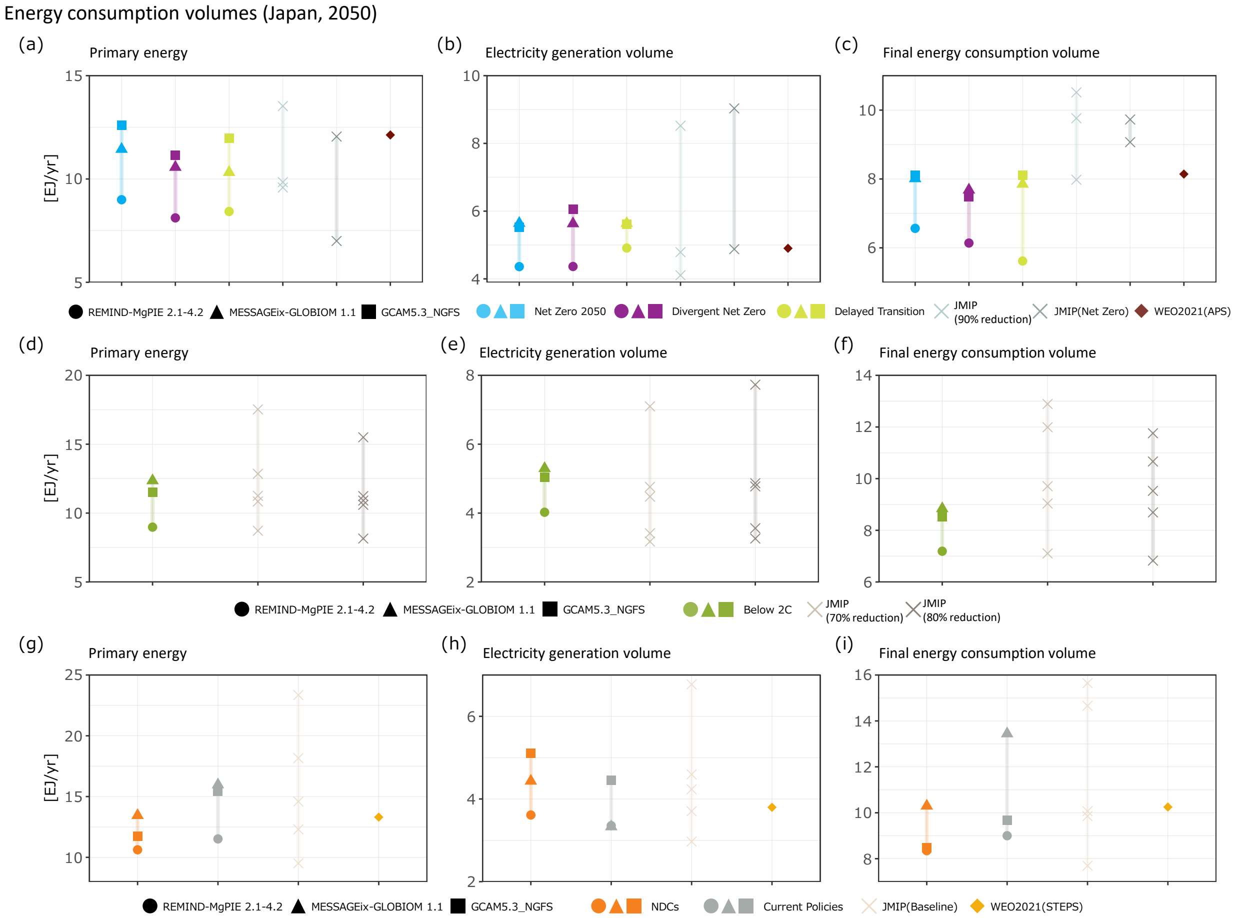

Figure 4.4.12 Energy (primary energy, electricity generation volume, and final energy) for each pair of scenarios compared (2050, Japan)

4.4.9 Primary Energy (fossil fuels)

__Worldwide (Figure 4.4.13)__

Net Zero 2050 (1.5ºC) and Divergent Net Zero (1.5ºC): Volumes of primary energy (fossil fuels) in the NGFS scenarios are mostly distributed within the ranges of volumes in the SR15 and WEO-2021 scenarios. However, regarding coal, volumes under REMIND-MAgPIE 2.1-4.2 and MESSAGEix 1.1 are located near the bottom of the range of volumes in the SR scenarios (volume of primary energy is near zero). With respect to gas as well, volume under REMIND-MAgPIE 2.1-4.2 is near the bottom of the ranges in the SR15 scenarios.

Below 2ºC (1.7ºC) and Delayed Transition (1.8ºC): Volumes of primary energy (fossil fuels) in the NGFS scenarios are distributed mostly within the ranges of volumes in the SR15 scenarios. However, regarding coal, volumes under REMIND-MAgPIE 2.1-4.2 and MESSAGEix 1.1 are near the bottom of the ranges of volumes in the SR15 scenarios (volume of primary energy consumption is near zero).

NDCs (2.5ºC) and Current Policies (3ºC+): Volumes of primary energy (fossil fuels) in the NGFS scenarios are distributed mostly within the ranges of volumes in the SR15 and WEO-2021 scenarios.

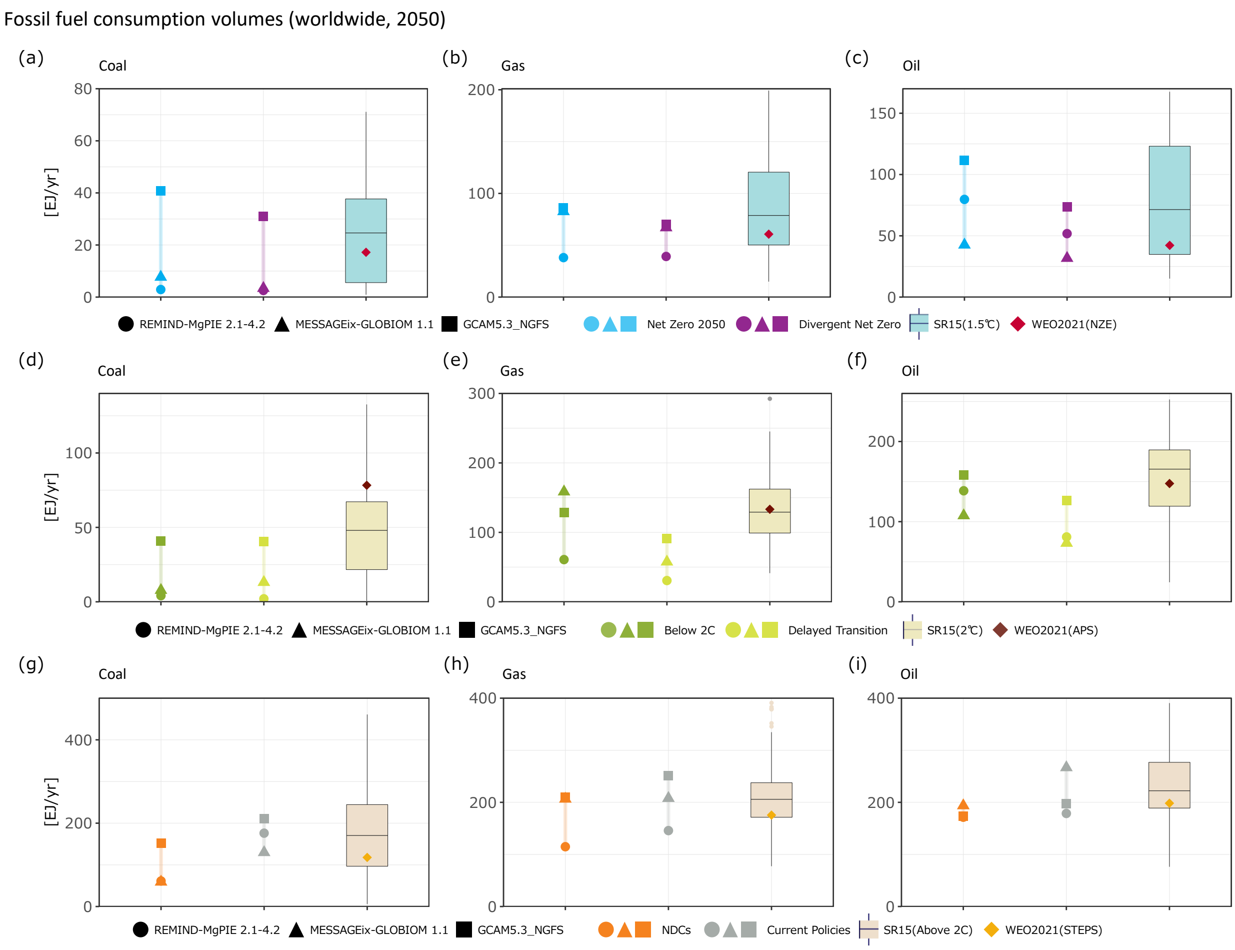

Figure 4.4.13 Fossil fuel consumption volumes for each pair of scenarios compared (2050, Worldwide)

Japan (Figure 4.4.14)

Net Zero 2050 (1.5ºC), Divergent Net Zero (1.5ºC), and Delayed Transition (1.8ºC): The ranges of volumes of primary energy in the NGFS scenarios appear to be consistent with the ranges in the JMIP and WEO-2021 scenarios, but the variance within each scenario is large. Volumes of coal under REMIND-MAgPIE 2.1-4.2 and MESSAGEix-GLOBIOM 1.1 in the NGFS scenarios are near zero. Regarding gas and coal, while volumes appears to be distributed mostly within the ranges in the JMIP and WEO-2021 scenarios, the volume under REMIND-MAgPIE 2.1-4.2 is smaller in Delayed Transition among the NGFS scenarios than in the JMIP and WEO-2021 scenarios.

Below 2ºC (1.7ºC): While the ranges of volumes of primary energy in the NGFS scenario appear to be consistent with the ranges in the JMIP and WEO-2021 scenarios, the variance of volumes across the IAMs is large within each scenario.

NDCs (2.5ºC) and Current Policies (3ºC+): Regarding coal, the volume in the NDCs among the NGFS scenarios is smaller than the volumes in the JMIP and WEO-2021 scenarios. As for gas and electricity, the ranges of volumes in the NGFS scenarios are mostly consistent with the ranges in the JMIP and WEO-2021 scenarios.

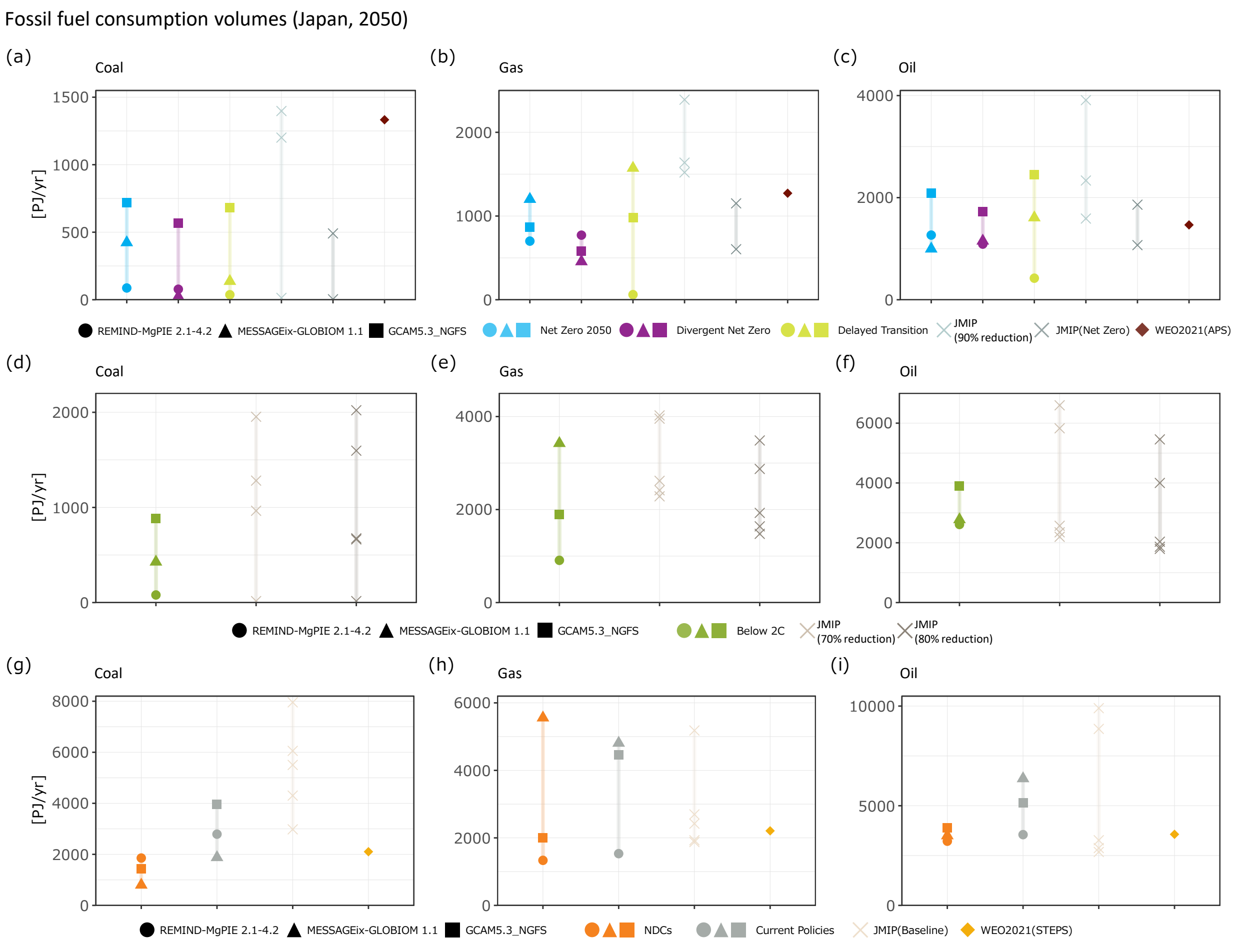

Figure 4.4.14 Fossil fuel consumption volumes for each pair of scenarios compared (2050, Japan)

4.4.10 Electricity Generation (Secondary Energy)

Worldwide (Figure 4.4.15)

Net Zero 2050 (1.5ºC) and Divergent Net Zero (1.5ºC): Electricity generation volumes in the NGFS scenarios are distributed mostly within the ranges of volumes in the SR15 scenarios. However, regarding wind power generation, volumes of electricity generation in the NGFS scenarios are concentrated near the top of the ranges in the SR15 scenarios, which means that electricity generation volumes in the NGFS scenarios are larger than the volumes in existing scenarios. On the other hand, with respect to BECCS and fossil fuel electricity generation with CCS, electricity generation volumes under REMIND-MAgPIE 2.1-4.2 and MESSAGEix-GLOBIOM 1.1 in the NGFS scenarios are located near the bottom of the ranges of volumes in the SR15 scenarios (electricity generation volume is almost zero), although the volume varies across the IAMs.

Below 2ºC (1.7ºC) and Delayed Transition (1.8ºC): Electricity generation volumes in the NGFS scenarios are distributed mostly within the ranges of volumes in the SR15 scenarios. However, with respect to wind and solar power generation, electricity generation volumes in the NGFS scenarios are concentrated near the top of the ranges of volumes in the SR15 scenarios. The volume of nuclear power generation under REMIND-MAgPIE 2.1-4.2 in the NGFS scenarios is small and is near the bottom of the ranges of volumes in the SR15 scenarios.

NDCs (2.5ºC) and Current Policies (3ºC+): Regarding wind and solar power generation, electricity generation volumes in the NGFS scenarios are concentrated near the top of the ranges of volumes in the SR15 scenarios. On the other hand, regarding nuclear power generation volumes in the NGFS scenarios are concentrated near the bottom of the SR15 scenarios.

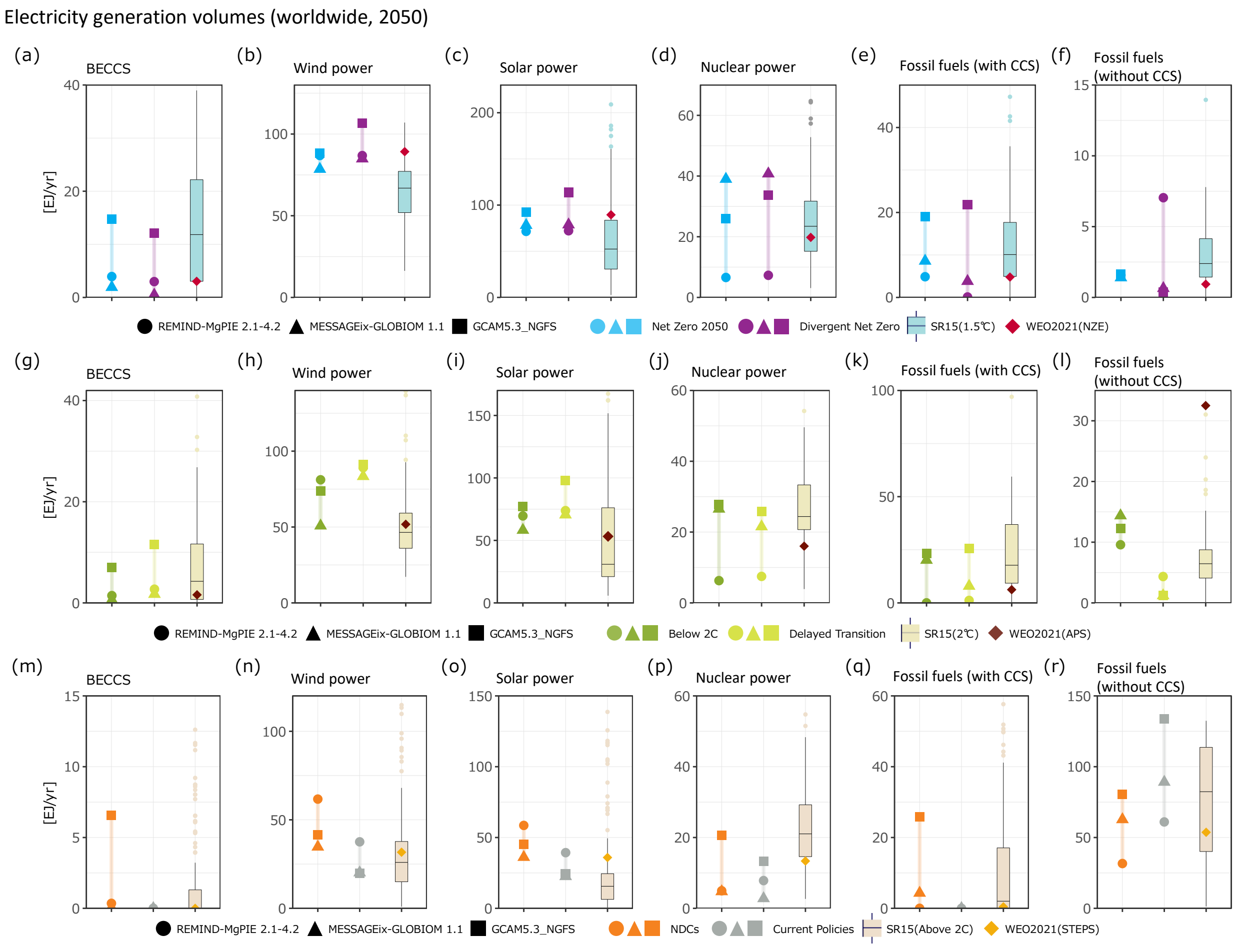

Figure 4.4.15 Electricity generation volumes for each pair of scenarios compared (2050, Worldwide)

Japan (Figure 4.4.16)

Net Zero 2050 (1.5ºC), Divergent Net Zero (1.5ºC), and Delayed Transition (1.8ºC): Electricity generation volumes in the NGFS scenarios are distributed mostly within the ranges of volumes in the JMIP and WEO-2021 scenarios, although the volumes may be outside those ranges under some IAMs. Regarding solar power generation, electricity generation volumes under MESSAGEix-GLOBIOM 1.1 and GCAM 5.3 are larger in the NGFS scenarios than in the JMIP and WEO-2021 scenarios. On the other hand, with respect to fossil fuel with CCS, electricity generation volumes under REMIND-MAgPIE 2.1-4.2 and GCAM 5.3 are smaller than in the JMIP and WEO-2021 scenarios.

Below 2ºC (1.7ºC): Electricity generation volumes in the NGFS scenario are distributed mostly within the ranges of volumes in the JMIP and WEO-2021 scenarios. However, regarding solar power generation, electricity generation volume under GCAM 5.3 is larger than in the JMIP and WEO-2021 scenarios.

NDCs (2.5ºC) and Current Policies (3ºC+): Regarding solar and nuclear power generation, the electricity generation volumes in the NGFS scenarios are distributed mostly within the ranges of volumes in the JMIP and WEO-2021 scenarios. In the NDCs scenario, some electricity generation capacity will be added for BECCS (GCAM 5.3), wind power (REMIND-MAgPIE 2.1-4.2), or fossil fuels with CCS (GCAM 5.3), depending on the IAM.

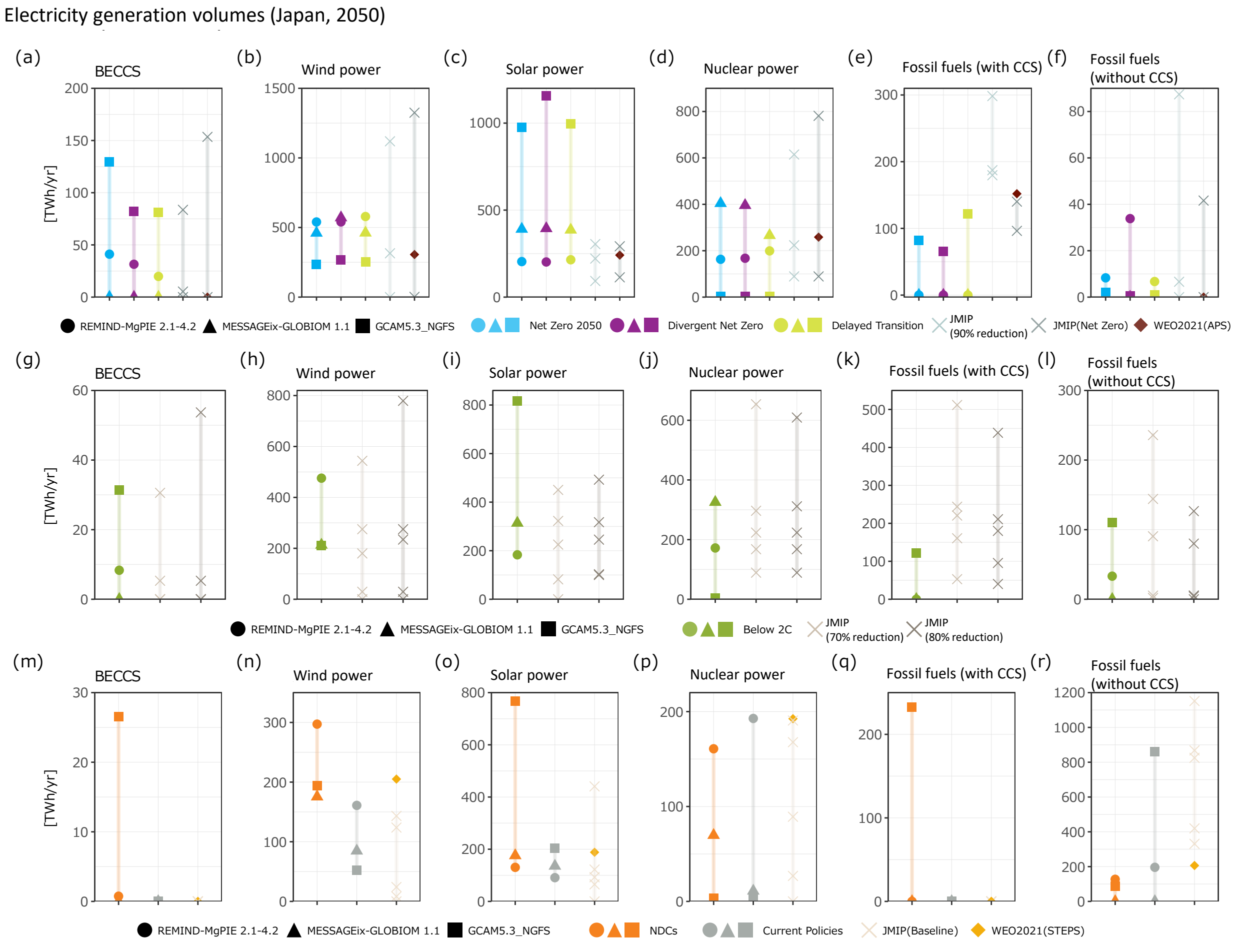

Figure 4.4.16 Electricity generation volumes for each pair of scenarios compared (2050, Japan)

4.4.11 Final Energy

Worldwide (Figure 4.4.17)

Net Zero 2050 (1.5ºC) and Divergent Net Zero (1.5ºC): The volumes of final energy consumption in the NGFS scenarios are distributed mostly within the ranges of volumes in the SR15 scenarios. However, the volumes of of liquid fuels in Divergent Net Zero are concentrated near the bottom of the ranges of volumes in the SR15 scenarios.

Below 2ºC (1.7ºC) and Delayed Transition (1.8ºC): The volumes of final energy consumption in the NGFS scenarios are distributed mostly within the range of volumes in the SR15 scenarios, However, the volumes of liquid fuels in Delayed Transition are concentrated near the bottom of the ranges of volumes in the SR15 scenarios.

NDCs (2.5ºC) and Current Policies (3ºC+): While the volumes of final energy in the NGFS scenarios are distributed mostly within the ranges of volumes in the SR15 scenarios, the volumes of gas in the NGFS scenarios are smaller and the volumes of coal are slightly larger than the volumes in the SR15 scenarios.

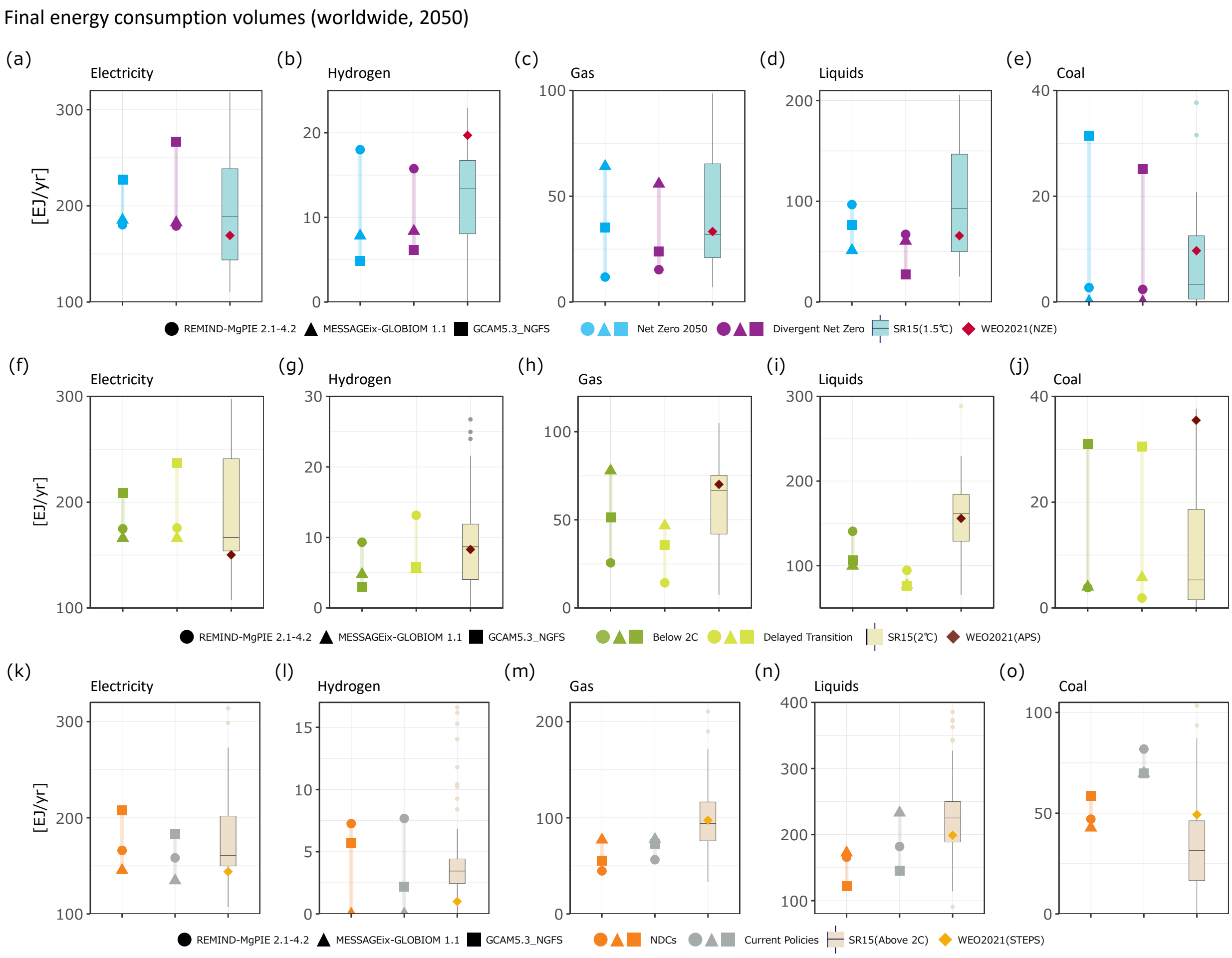

Figure 4.4.17 Final energy consumption volumes for each pair of scenarios compared (2050, Worldwide)

Japan (Figure 4.4.18)

Net Zero 2050 (1.5ºC), Divergent Net Zero (1.5ºC), and Delayed Transition (1.8ºC): The volumes of final energy consumption in the NGFS scenarios are distributed mostly within the ranges of volumes in the JMIP and WEO-2021 scenarios. However, the ranges of volumes are narrower and the highest value of volume is lower in the NGFS scenarios than in the JMIP and WEO-2021 scenarios.

Below 2ºC (1.7ºC): Although the volumes of final energy consumption in the NGFS scenario are distributed mostly within the ranges of volumes in the JMIP and WEO-2021 scenarios, the distribution ranges in the NGFS scenario are narrower.

NDCs (2.5ºC) and Current Policies (3ºC+): The volumes of final energy in the NGFS scenarios are distributed mostly within the ranges of volumes in the JMIP and WEO-2021 scenarios. However, the volumes of hydrogen in the NGFS scenarios are larger than the volumes in the JMIP scenarios. Although there will be residual coal consumption in 2050 in the NGFS scenarios, the volumes of coal consumption in some of the JMIP scenarios in 2050 will be almost zero.

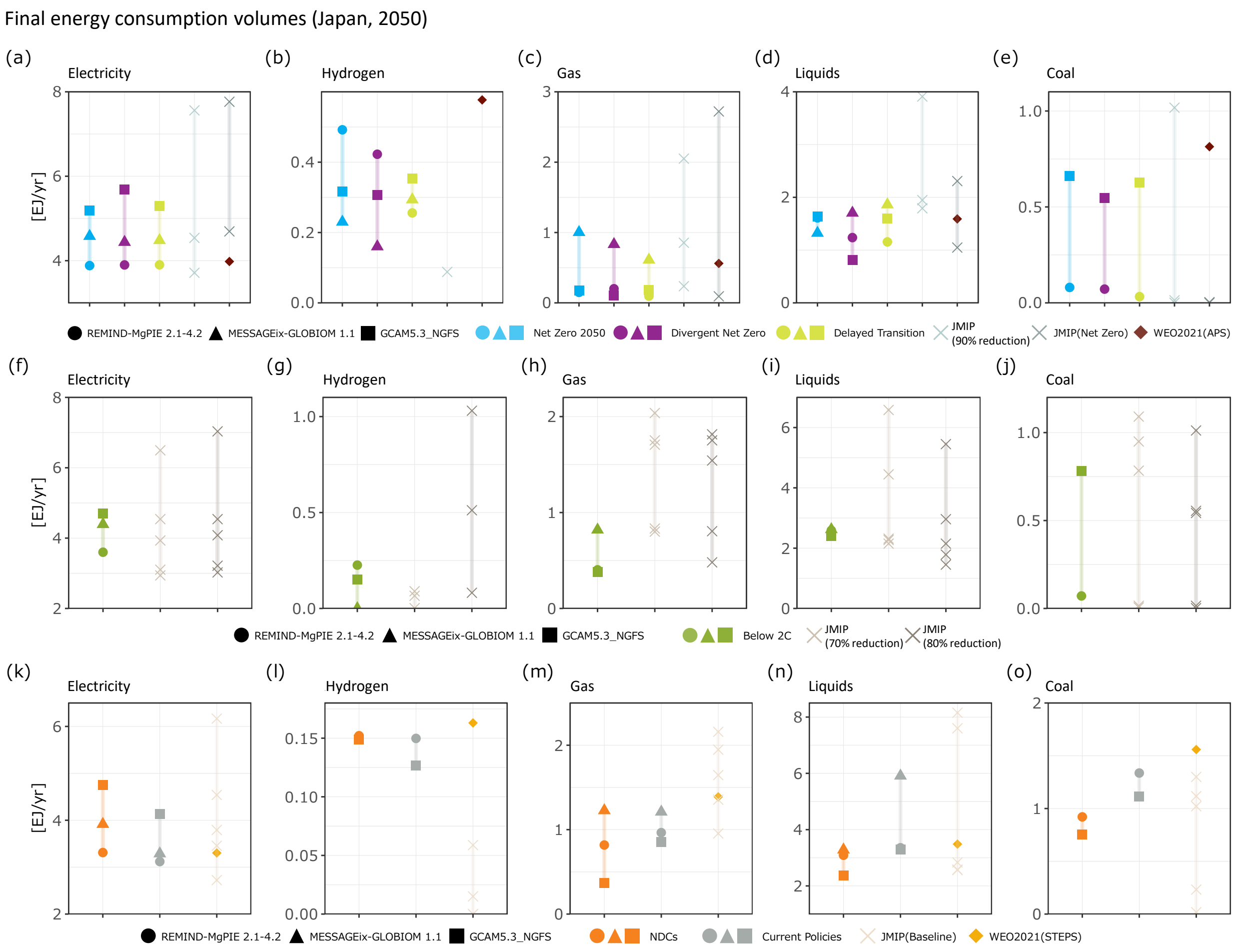

Figure 4.4.18 Final energy consumption volumes for each pair of scenarios compared (2050, Japan)

4.4.12 Summary: Comparison with Existing Scenarios

This section compared the key variables of the NGFS Scenarios (Phase 2) and existing scenarios for the world and for Japan. As a result, no significance difference was observed between the key variables of the compared scenarios in terms of CO_2 emission and CO_2 removal volume by sector and primary energy, secondary energy (electricity generation volume) and final energy consumption volume by sector. Therefore, it may be said that the NGFS Scenarios (Phase 2) are consistent, in terms of the ranges of those key variables, with existing scenarios in which a similar level of emission reduction is expected.

On the other hand, there were clear differences in terms of the carbon price levels. Specifically, the carbon price levels set in the WEO-2021 scenarios which assume introduction of ambitious emission reduction policies are conspicuously lower than the price levels set in comparable NGFS and other scenarios (e.g., Net Zero 2050) (Figures 4.4.3 and 4.4.4). This is because of a difference in the method of determining the carbon price. Under the World Energy Model, which is a simulation model used in the WEO-2021, the carbon price is determined exogenously in reference to the price level that triggers a change in energy demand by realigning the relative cost by type of fuel under the assumption of introduction of a policy measure that contributes to emission reduction other than carbon pricing, or the price level under current policies (IEA, 2021a). On the other hand, under many IAMs, the carbon price is endogenously calculated at the level at which the conditions of emission constraints are satisfied (see Section 7.2 as well). With respect to Japan, the carbon prices calculated under the JMIP are higher than the prices under the NGFS Scenarios (Phase 2) (Figure 4.4.4). One possible reason is the difference in cost assumptions regarding emission reduction technology between the JMIP scenarios and the NGFS Scenarios (Phase 2).

5 Examples of Use of the NGFS Scenarios by Supervisory Authorities and Central Banks

5.1 Overview of Example of Risk Analysis by Supervisory Authorities and Central Banks

As of October 2021, regulatory authorities and central banks in 30 countries had conducted climate change-related financial risk analysis or were planning to do so. Most of them have already used the NGFS scenarios or have expressed an intention to do so (NGFS, 2021c). In this report, we take up six examples by five organizations that have disclosed methodologies for and the results of analysis of transition risks using the integrated assessment models and the NGFS scenarios (Table 5.1.1).

Table 5.1.1 Examples of use of NGFS scenarios by foreign supervisory authorities and central banks[20]

Implementing organization (country)	Name (abbreviation)	Timing of completion	Approach	Balance sheet assumption	Level of analysis	Period of analysis
Autorité de contrôle prudential et de resolution (ACPR) / Banque de France (France)	ACPR Climate Pilot Exercise (ACPR 2021)	May 2021	Bottom-up	Hybrid	Sector (55 sectors)	30 years
European Central Bank (euro area)	ECB Economy-wide climate stress test (ECB 2021)	September 2021	Top-down	Static	Counterparty	30 years
	ECB SSM stress test (ECB 2022)	2022	Bottom-up	Short term: static Long term: dynamic	Counterparty	Short-term: 3 years Long term: 30 years
Bank of England (United Kingdom)	BoE Biennial Exploratory Stress test (BoE 2022)	May 2022 (planned)	Bottom-up	Static	Counterparty/macroeconomics/ sector	30 years
Bank of Canada (Canada)	BoC-OSFI Climate Scenario Analysis Pilot (BoC-OFSI 2022)	January 2022	Bottom-up /top-down	Static	Counterparty/sector	30 years
Australian Prudential Regulation Authority (Australia)	APRA Climate Vulnerability Assessment (APRA 2022)	1st half of 2022 (planned)	Bottom-up/top-down	Hybrid	Counterparty/macroeconomics/ sector	30 years

5.1.1 ACPR / Banque de France (France)

ACPR Climate Pilot Exercise (ACPR 2021)

The ACPR (Autorité de contrôle prudential et de résolution, a French prudence regulator), together with Banque de France (the French central bank), published the methodology for climate-related risk analysis based on the NGFS

[20] This table shows a summary of some of the analysis methodologies and results which have been published in reports by financial supervisory authorities and central banks and which were presented in NGFS (2021c).

scenarios (ACPR, 2020; Allen et al., 2020) in July 2020 through April 2021 and announced the results of the analysis in May 2021 (ACPR, 2021).

The subjects of analysis were banks and insurance companies located in France. For this analysis, the regulatory authorities adopted a "bottom-up approach," under which the analyzed banks and insurance companies cooperated with the authorities in conducting financial analysis.[21] The analysis period was the 30 years from 2020 to 2050. Transition risks in each of 55 sectors were analyzed based on three scenarios with different pathways toward decarbonization.

Regarding the balance sheet assumptions analyzed, a hybrid approach, which combines static and dynamic approaches, was adopted. More specifically, for the period until 2025, the static approach that has been adopted under a traditional stress test framework for financial institutions, was adopted, and for the period from 2025 onwards, dynamic balance sheet assumptions were made.

5.1.2 European Central Bank (Euro area)

In 2021, the ECB (European Central Bank) published the results of or plans for two sorts of risk analysis using different approaches.

ECB Economy-wide climate stress test (ECB 2021)

First, an analysis regarding the whole of the euro area was conducted, and the preliminary results were announced in March 2021, followed by the announcement of the final results in September of the same year (ECB, 2021a).

The subjects of analysis were banks located in the euro-area countries, and the analysis was conducted under a "top-down approach," with the ECB measuring and analyzing financial institutions' risks based on external databases. The analysis period was the 30 years until 2050.

The scope of analysis covered both physical and transition risks, and three scenarios—one baseline scenario and two scenarios in which the effects of either physical or transition risks appear more prominently—were prepared. Based on those scenarios, credit risk (probability of default [PD] and loss given default [LGD]) for each counterparty (non-financial company) was modeled. Regarding banks' balance sheets, a dynamic approach was adopted.

ECB SSM stress test (ECB 2022)

In October 2021, the ECB announced a plan to implement a climate stress test as part of the annual stress test conducted under the Single Supervisory Mechanism (SSM) and published the methodology (ECB, 2021b). The climate stress test was intended mainly to enable both banks supervised under the SSM and regulatory authorities to improve their ability to assess climate-related risks. It is characterized as a joint learning exercise between the ECB and supervised banks.

The stress test under the SSM will be conducted through a bottom-up approach. Banks subject to the stress test are required to fill in and submit the template provided by the ECB with necessary information. The template is comprised of three parts: qualitative information regarding banks' climate-related risks (Module 1), and climate-related quantitative

[21] Although ACPR (2021) classified this method as a "bottom-up approach" because the stress test was conducted with the participation of financial institutions, it can be said that the method includes an element of a "top-down approach" due to the use of models and approaches prescribed by the authorities in quantitative risk analysis.

benchmarks (Module 2), and the results of a stress test using the scenarios provided by the ECB (Module 3). Among the banks subject to the 2022 climate stress test, all of those that are equivalent to "significant institutions" must provide information concerning Module 1 and Module 2. While only some of those banks are obligated to provide information concerning the stress test based on climate scenarios (Module 3), the ECB has asked all participating banks to provide data necessary for implementing the stress test regarding Module 3.

In January 2022, the ECB officially published the scenarios.[22] The stress test is scheduled to be conducted in March through July 2022. Data submitted by participating organizations will be integrated after close examination of data quality by the ECB and be published in a report.

The stress test will be conducted with two time horizons, i.e., a short-term period (three years) and a long-term period (30 years). Under the short-term time horizon (three years), the stress test will be conducted using the same framework as the one used in a traditional stress test. Transition risk (shock) due to a rapid rise in the carbon price must be analyzed based on static balance sheet assumptions.

On the other hand, under a long-term time horizon (30 years), the stress test covers both physical and transition risks. The approach to balance sheets is dynamic, with banks subject to the test required to describe exposures to companies and mortgages in 2030, 2040 and 2050.

5.1.3 Bank of England (U.K.)

2021 Biennial Exploratory Scenario (BoE 2022)

In December 2019, the Bank of England (BoE) announced a plan to conduct climate-related risk analysis under the framework of a biennial exploratory stress test (Biennial Exploratory Scenario), which is conducted separately from the standard annual stress test (Annual Concurrent Stress Test) and published the scenarios and analysis methodology on a preliminary basis (BoE, 2019). This analysis covers major U.K. banks and non-life insurance companies and transition and physical risks. Initially, the analysis was scheduled to be conducted starting in the first half of 2020, but implementation has been postponed for one year in order to give precedence to response to the COVID-19 crisis. The methodology was published in June 2021 (BoE, 2021), and the analysis results are scheduled to be published around May 2022.

The stress test covers U.K. banks and insurance companies and both physical and transition risks. The analysis will be conducted under a "bottom-up approach." Risk analysis must be conducted with respect to credit risk related to banking accounts (risk related to counterparties that are large companies in particular) in the case of banks and with respect to shock event risk for investment assets and insurance liabilities (including payment of reinsurance benefits and underwriting of reinsurance contracts) in the case of insurance companies.

Different time horizons of analysis are used for physical and transition risks. Regarding physical risks, scenarios with time horizons of up to 60 years (until 2080) have been prepared in order to assess the impact of risks that may appear after 2050. On the other hand, the analysis period regarding transition risks is 30 years (until 2050). Balance sheet assumptions

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[22] ECB. ECB Banking Supervision launches 2022 climate risk stress test.
https://www.bankingsupervision.europa.eu/press/pr/date/2022/html/ssm.pr220127~bd20df4d3a.en.html (last access: March 22, 2022)

are static.

5.1.4 Bank of Canada (Canada)

Climate Scenario Analysis Pilot (BoC-OSFI 2022)

In November 2020, the Bank of Canada (BoC) and the Office of Superintendent of Financial Institutions (OSFI) announced a plan to implement a climate-related risk analysis pilot project with respect to six financial institutions (two banks, two life insurance companies, and two non-life insurance companies) that are under the supervision of the federal government. In January 2022, the detailed analysis approach, scenarios, and analysis results were published (BoC-OFSI, 2022; Chen et al., 2022; Hosseini et al., 2022).

The analysis covered transition risks related to some assets located in Canada and the United States (in the case of some financial institutions, risk analysis was conducted with respect to assets located outside North America as well), with 10 high emitting sectors (crops, forestry, livestock, coal, oil, gas, refined oil, electricity, energy-intensive industries, and commercial transportation) selected for analysis. The analyzed assets accounted for 5% of overall assets on the balance sheets in the case of banks and 15% in the case of insurance companies (BoC-OFSI, 2022).

The analysis approach was a hybrid one combining "top-down and bottom-up approaches." In the top-down process of the risk analysis, the BoC first calculated the macro-level financial impact by sector and by region. In the bottom-up process of the analysis, financial institutions under analysis were required to select at least five representative borrowers in each portfolio segment and conduct quantitative assessment of credit risk (PD and LGD). The borrowers analyzed in the bottom-up process accounted for 28% of overall assets in the 10 sectors.

The analysis period was 30 years (until 2050) and balance sheet assumptions were static.

5.1.5 Australian Prudential Regulation Authority (Australia)

Climate Vulnerability Assessment (APRA 2022)

The Australian Prudential Regulation Authority (APRA) started a consultation process[23] regarding guidance on climate-related financial risk supervision in April 2021 and published the finalized guidance in November of the same year (APRA, 2021). In parallel, APRA started developing a framework of climate-related risk analysis and published its outline in September 2021.

The stress test covers banks located within Australia and both physical and transition risks. While the subjects of analysis are exposures to mortgage loans and companies located within Australia, exposures in New Zealand and the rest of the world may also be included in the scope of analysis. The period of analysis is 30 years (from 2020 to 2050). Balance sheet assumptions include both static and dynamic assumptions.

5.2 NGFS Scenarios Used for Analyses

First, a comparison will be conducted to find out which NGFS scenarios are used by which financial supervisory

[23] Media Release: APRA releases guidance on managing the financial risks of climate change (https://www.apra.gov.au/news-and-publications/apra-releases-guidance-on-managing-financial-risks-of-climate-change) (last access: March 22, 2022)

authorities and central banks in their risk analysis.

Table 5.2.1 is a list of the NGFS scenarios used in the six cases of risk analysis conducted by the five organizations. Of those cases, two cases —ACPR (2021) and ECB (2021)—used the NGFS Scenarios (Phase 1) for reference, while the remaining four used the NGFS Scenarios (Phase 2).

The following three scenarios are widely used across the six cases of analysis: Net Zero 2050 (which corresponds to Orderly Transition in Phase 1 and to Below 2ºC in Phase 2), Delayed Transition (which corresponds to Disorderly Transition in Phase 1), and Current Policies (which corresponds to Hot House World in Phase 1). Of those scenarios, Net Zero 2050 is used as a baseline case. Delayed Transition is used to represent a case in which transition risk materializes more prominently, while Current Policies is used to represent a case in which physical risk materializes more prominently.

While supervisors' and/or banks' own scenarios were developed based on the NGFS scenarios in each case of risk analysis, there are differences in terms of how the NGFS scenarios are used for analyses. In ACPR (2021), ECB (2021), ECB (2022), BoE (2022), and APRA (2021), distinctive variables that express transition pathways in the NGFS scenarios (e.g., carbon price and greenhouse gas emission volume) were selected, and variables which have been derived supervisors' and/or banks' in-house calculation were developed in ways that complement those variables.

On the other hand, it was found that some of the scenarios used in ACPR (2021) were developed by making adjustments to carbon prices in the NGFS scenarios. In BoC−OFSI (2022), bank's own scenarios were developed under integrated assessment models different from the ones adopted in the NGFS scenarios even though the narratives and the carbon price pathways in the NGFS scenarios were used for reference. Below, the abovementioned original approaches to using NGFS scenarios for reference will be explained.

Table 5.2.1 List of NGFS scenarios used for reference by financial supervisory authorities and central banks

Scenario		ACPR (2021)	ECB (2021)	ECB (2022)	BoE (2022)	BoC-OSFI (2022)	APRA (2022)
NGFS (Phase 1)	Orderly Transition	○	○				
	Disorderly Transition	○	○				
	Disorderly Transition (alternative)	△	-				
	Hot House World	-	○				
NGFS (Phase 2)	Net Zero 2050			○	○	△*1	-
	Below 2°C			-	-	△	-
	Divergent Net Zero			-	-	△*1	-
	Delayed Transition			○	○	△	○
	NDC			-	-	-	-
	Current Policies			○	○	△	○

○: The scenarios were developed using the values of carbon price, emission volume and other variables of the NGFS scenarios.

△: The scenarios were developed by adjusting the values in the NGFS scenarios or by using only the narratives of those scenarios for reference.

*1. Net Zero 2050 and Divergent Net Zero were used for reference in developing the same scenario.

Adjustment of NGFS scenarios in ACPR (2021)

The published documents indicate that in ACPR (2021), one of the three scenarios was developed by making adjustments to the NGFS scenarios. More specifically, in the "Sudden transition" scenario, the economic impact due to rapid transition is expressed by delaying by five years the trajectory of carbon price increase projected under an IAM (REMIND-MAgPIE) in the NGFS Scenarios (Phase 1) (while the carbon price starts to rise in 2020 in the Disorderly Transition scenario of the NGFS Scenarios (Phase 1), the start of the transition point is delayed from 2020 to 2025 in Sudden Transition in ACPR (2021) (Figure 5.2.1, right-side graph; orange color●).

Table 5.2.2 Narratives of the transition scenarios of ACPR (2021)

ACPR scenario	NGFS scenario used as a basis	Narrative
Orderly transition	Orderly transition (Representative scenario)	Corresponds to Orderly transition among the NGFS scenarios. As the narrative is consistent with France's low carbon transition strategy (Stratégie Nationale Bas Carbone), net zero emissions will be achieved by 2050 in line with the Paris Agreement goal.
Delayed policy action	Disorderly transition (Representative scenario)	As a result of failure to achieve the goal for 2030 and the immaturity of CCS technology, the government will raise the carbon price in order to implement the goal of achieving carbon neutrality by 2050.
Sudden transition	Disorderly transition (Alternative scenario)	Rapid transition will start in 2025 while technological development is still immature and productivity will decline due to investment in high-cost technology.

Underlined sentence: An original narrative set by ACPR.

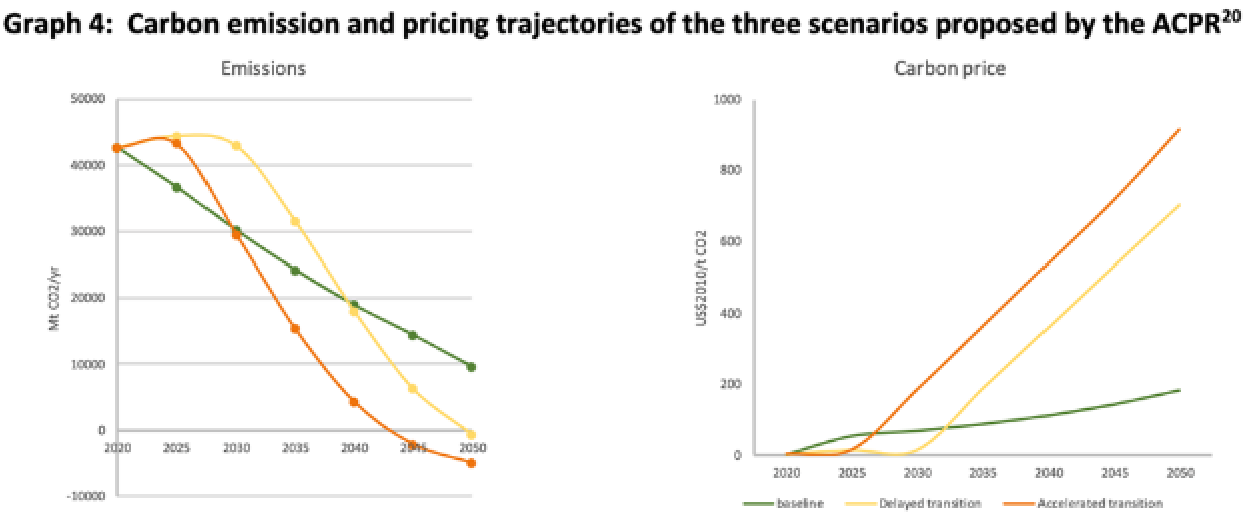

Figure 5.2.1 Carbon emission and price pathways in the NGFS Scenarios (Phase 1) used for reference in ACPR (2021). The symbols in the figure correspond to the scenarios in Table 5.2.2 as follows: Baseline●→Orderly transition, Delayed Transition●→Delayed policy action, Accelerated transition●→Sudden Transition

Use of NGFS scenarios for reference, and own scenarios in BoC-OFSI (2022)

In BoC-OFSI (2022), while the narratives and key variables of NGFS scenarios were used for reference, own scenarios were developed using an IAM not adopted by NGFS (Table 5.2.3).

Among notable features about the narratives of BoC-OFSI are the assumption of policy introduction and technological innovation that is in line with NGFS scenarios and the presence of original narratives in the forestry sector. In the baseline scenario (which corresponds to Current Policies among the NGFS scenarios), as a result of the policy adopted as of the end of 2019 being maintained, sufficient investment will not be made in the forestry sector, with the result that forests will remain a net emission source until the middle of the 21st century (forest degradation and harvesting activities will continue on a scale larger than carbon fixation through forests). On the other hand, in scenarios where the goal of keeping the level of temperature rise below 2ºC and below 1.5ºC, respectively, will be achieved, it is clearly assumed that forests will become a net absorption source by the middle of this century.

Meanwhile, in the Net-zero 2050 scenario in BoC-OFSI (2021), the current goal of reducing emissions to net zero in Canada and other countries was explicitly modeled.

In BoC-OFSI (2021), scenario variables were calculated using an integrated assessment model called EPPA, which was developed by the Massachusetts Institute of Technology. Consistency with the NGFS scenarios was ensured by showing that the global emission pathways under EPPA are located within the range of emission pathways in the NGFS scenarios used for reference (indicated by the green■ line in Figure 5.2.2) (Chen et al., 2022).

Table 5.2.3 NGFS scenarios and narratives used for reference in BoC-OFSI (2022)

BoC-OFSI (2022) scenario	NGFS scenario used for reference	Narrative
Baseline (2019 policies)	Current Policies	• The world will follow the pathway under the climate policy launched at the end of 2019 and the average worldwide temperature will rise by a range of 2.9 to 3.1°C by 2100. • Forestry will remain a net emission source until the middle of the 21st century on a worldwide basis. • The pace of technological innovation will be slow. • Availability of CO_2 removal technology will be limited.
Below 2ºC immediate	Below 2ºC	• Actions to keep the temperature rise at the end of the 21st century below 2ºC will start in 2020. • As a result of early investment and forest planning and management, forests will become a net absorption source, albeit on a small scale, by the middle of the 21st century. • The pace of technological innovation will be moderate. • Availability of CO_2 removal technology will be limited.
Below 2ºC delayed	Delayed Transition	• Actions to keep the temperature rise at the end of the 21st century below 2ºC will start in 2030, after the policy launched at the end of 2019 has been continued for 10 years. A more rapid transition will be necessary to make up for the 10 years of emission increase. • As a result of delays in introducing investment and forest planning and management, forests cannot become a net absorption source by the middle of the 21st century. • The pace of technological innovation will be moderate. • Availability of CO_2 removal technology will be limited.
Net-zero 2050 (1.5ºC)	Net Zero 2050, Divergent Net Zero	• Actions to keep the temperature rise at the end of the 21st century below 1.5ºC will be taken. Current net zero goals, including the Canadian one, were directly modeled in this scenario. • As a result of intense initial investment, forests will become a net absorption source by the middle of the 21st century. • The pace of technological innovation will be quick. • Availability of CO_2 removal technology, including BECCS (bioenergy with CCS), will be at a medium level.

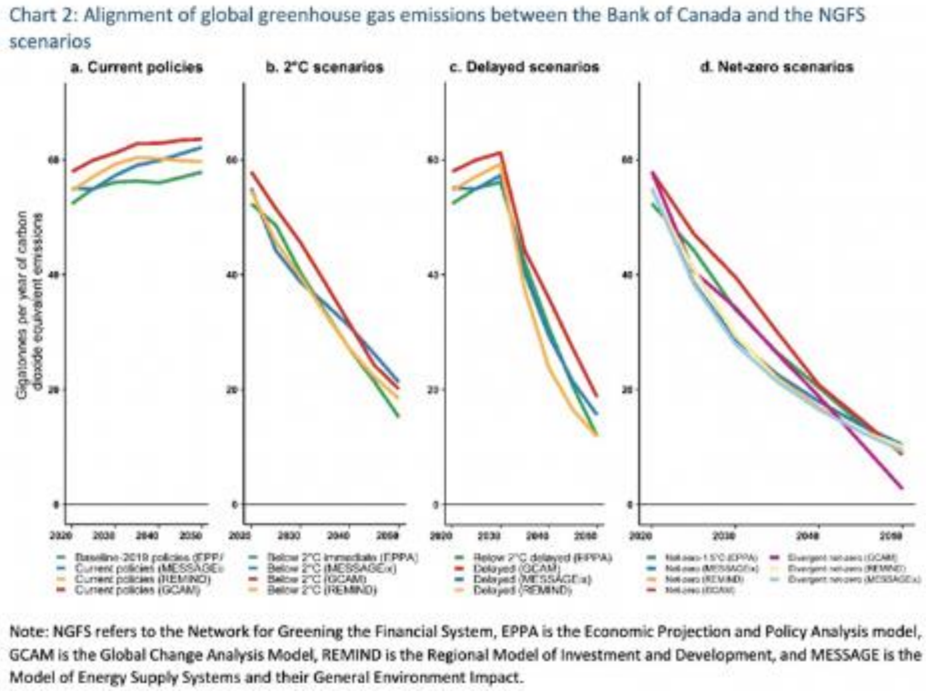

Figure 5.2.2 Comparison of GHG emission pathways in the NGFS scenarios that correspond to the scenarios of BoC-OFSI (2022)

5.3 Integrated Assessment Models Adopted

Of the three integrated assessment models adopted by NGFS, REMIND-MAgPIE was adopted by the financial supervisory authorities and central banks in Europe. On the other hand, GCAM was adopted in whole by APRA of Australia. This is presumably because GCAM, under which Australia and New Zealand are classified collectively as one native region, was convenient for APRA, whose analysis mainly covered Australia and New Zealand (under REMIND-MAgPIE, Canada, Australia and New Zealand are classified as one single native region, as are Japan, Australia and New Zealand under MESSAGEix-GLOBIOM).

In BoC-OFSI (2022) of Canada, in which an bank's own IAM was adopted, alignment check was conducted with the outcomes of the three IAMs adopted by NGFS in order to verify consistency between the model developed for this analysis and the NGFS scenarios (Figure 5.2.2).

Table 5.3.1 IAMs adopted by financial supervisory authorities and central banks

Integrated assessment model	ACPR (2021)	ECB (2021)	ECB (2022)	BoE (2022)	BoC-OFSI (2022)	APRA (2022)
REMIND-MAgPIE	○	○	○	○	△	-
MESSAGEix-GLOBIOM	-	-	-	-	△	-
GCAM	-	-	-	-	△	○
Models other than the NGFS models	-	-	-	-	○	-

○: The scenarios were developed based on the outputs of the IAM.
△: The scenarios were developed in reference to the outputs of the IAM.

5.4 Variables Used for Analysis of Transition Risk

Table 5.4.1 shows a summary of variables related to transition risk and data sources with respect to risk analyses conducted by supervisory authorities and central banks.

While different variables were used depending on the risk analysis approach and the analysis subject, the carbon price was used in all cases of analysis. With respect to the carbon price, data regarding the NGFS scenarios was adopted in all cases of analysis using those scenarios for reference except for BoC-OFSI (2022), which adopted an IAM other than those adapted by the NGFS. This means that from the viewpoint of analysis of transition risk, the carbon price is the most important variable.

On the other hand, with respect to most variables other than the carbon price, financial supervisory authorities and central banks made adjustments to the data of the NGFS scenarios or adopted additional data based on their own, in-house calculations. Regarding variables related to transition risk, it is noted in ECB (2021), ECB (2022), and BoE (2022) that adjustments were made to such variables as energy prices and energy demand based on NGFS scenarios. In BoE (2021), an own variable related to the automotive sector not included among the variables of the NGFS scenarios was adopted (to be later explained).

With respect to macroeconomic variables, financial supervisory authorities and central banks obtained data from external data providers or made own, in-house calculations. Among the six cases of analysis examined, macroeconomic variables were incorporated into scenarios in four cases, i.e., ACPR (2021), ECB (2022), BoE (2022), and BoC-OFSI (2022).

Table 5.4.1 Transition risk-related variables used in risk analysis by supervisory authorities and central banks, and data sources

Category	Variable	ACPR (2021)	ECB (2021)	ECB (2022) (Short term)	ECB (2022) (Long term)	BoE (2022)	BoC-OFSI (2022)	APRA (2022)
Transition risk variable	GHG emission volume	NGFS	ECB / Urgentem	-	NGFS	-	EPPA	RCP2.6 / RCP4.5 / RCP8.5
	Carbon price	NGFS / ACPR	NGFS	NGFS	NGFS	NGFS	EPPA	NGFS
	Energy prices	-	ECB	-	NGFS / ECB	NGFS / NIESR / BoE	EPPA	-
	Energy demand (primary and final)	-	ECB	-	-	NGFS	EPPA	-
	Energy mix (primary and electricity)	-	-	-	NGFS / ECB	-	EPPA	AEMO / NGFS
	Energy production cost	-	-	-	-	-	EPPA	-
	Number of newly registered vehicles	-	-	-	-	BoE	-	-
	Number of registered vehicles	-	-	-	-	BoE	-	-
	Used vehicle price	-	-	-	-	BoE	-	-
Macro-economic variable	Production volume (GDP, total value added, sales, etc.)	NIESR / BdF	ECB	ECB	ECB	Refinitiv Eikon / NIESR / BoE / etc.	EPPA / BoC	-
	Inflation rate and price index	NIESR	-	ECB	ECB	Refinitiv Eikon / NIESR / BoE / etc.	BoC	-
	Unemployment rate	NIESR	-	ECB	ECB	Refinitiv Eikon / NIESR / BoE / etc.		-
	Housing price	-	-	ECB	ECB	Refinitiv Eikon / NIESR / BoE / etc.		-
	Commercial real estate price	-	-	ECB	ECB	BoE / etc.		-
	Government expenditure	-	-	ECB	ECB	-		-
	Value of outstanding government debt	OECD / NIESR	-	-	-	-		-
	Budget deficit	OECD / NIESR	-	-	-	-		-
	Household income	-	-	ECB	ECB	Refinitiv Eikon / NIESR / BoE / etc.		-
	Exchange rate	-	-	ECB	ECB	BoE		-
	Short-term interest rate	-	-	ECB	ECB	Refinitiv Eikon / NIESR / BoE / etc.		-
	Government bond yield	-	-	ECB	ECB	Bloomberg / BoE		-
	Corporate bond yield and the spread	RMI / BoF	-	ECB	ECB	ICE/BofA ML Global Research / BoE		-
	Stock price index	NiGEM / BoF	-	ECB	ECB	Bloomberg / BoE		-

[Data sources]
NGFS Scenarios (Versions 1 and 2): NGFS
Financial supervisory authorities and central banks: ACPR/ BdF (France), ECB (euro area), BoE (U.K.), and BoC (Canada)
Public organizations and research centers: OCED and AMEO (Australian Energy Market Operator)
Research institutions and think tanks: NIESR (National Institute of Economic and Social Research of the United Kingdom), RMI (Risk Management Intelligence, National University of Singapore), and EPPA (EPA Model, Massachusetts Institute of Technology)
Data provides: Urgentem, Refinitiv Eikon, ICE/BofA ML Global Research, and Bloomberg

Linkage with a Macroeconomic Model (NiGEM) and a Sectoral Model (ACPR (2021))

In ACPR (2021), which was developed based on Phase 1 of the NGFS Scenarios, country-by-country macroeconomic variables (GDP, the inflation rate, and the unemployment rate) and sector-by-sector total value added and turnover were calculated using carbon prices in the NGFS scenarios under a macroeconomic model (NiGEM)[24] and a sectoral model

[24] This represents an original improvement made by ACPR, as the NGFS Scenarios (Phase 1) does not include forecasts of macroeconomic impacts calculated under NiGEM. As the idea of linking the outputs of the IAMs to macroeconomic

developed by Banque de France (BdF) (Devulder and Lisack, 2020). Those variables were ultimately incorporated into an internal model of Banque de France in order to estimate credit and market risks (Figure 5.4.1).

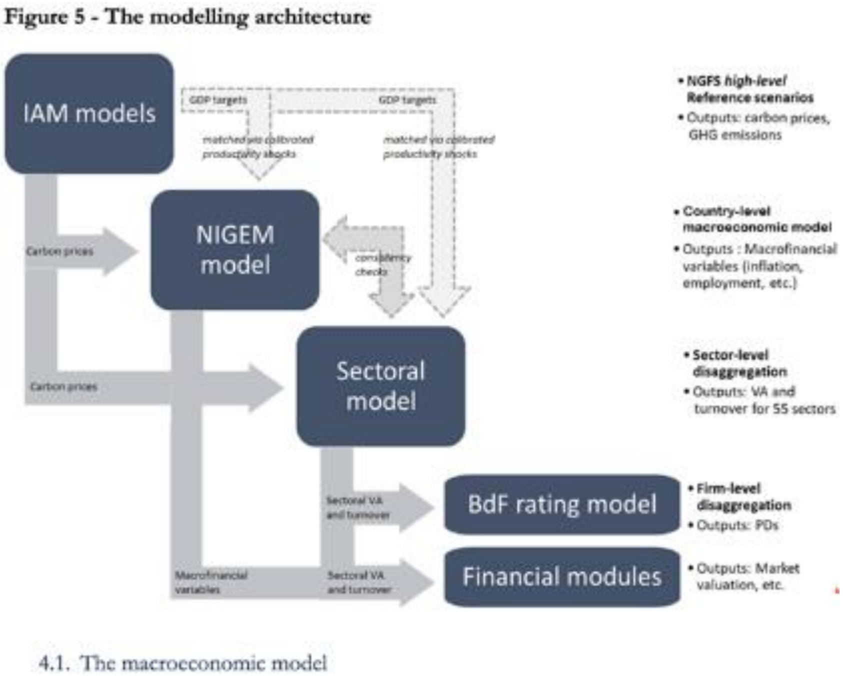

Figure 5.4.1 The modeling architecture of climate-related risk analysis by ACPR

<u>Share by type of vehicle (BoE (2022))</u>

In BoE (2022), variables not included among the variables of the NGFS scenarios, such as the number of vehicles newly registered, the number of registered vehicles and used vehicle price by type of vehicle (internal combustion engine, hybrid, and EV) in the United Kingdom, were adopted as additional variables. For the period before 2020, actual figures compiled by the U.K. Department of Transport were used as the values of those variables, and for the period from 2020 onwards, pathways consistent with the U.K. government's policy goal were set in all scenarios. More specifically, it was assumed that new vehicle sales will be discontinued (the number of newly registered vehicles will fall to zero) in 2030 for internal combustion engine vehicles and in 2035 for hybrid vehicles and that 100% of new vehicles sold from 2035 onwards will be EVs. While there are not significant differences between the scenarios, the share of hybrid vehicles is somewhat higher in the Early Action scenario than in the other two scenarios (Figure 5.4.2).

models was adopted in the NGFS Scenarios (Phase 2), which was published in June 2021, the outputs of NiGEM are available for use as native data.

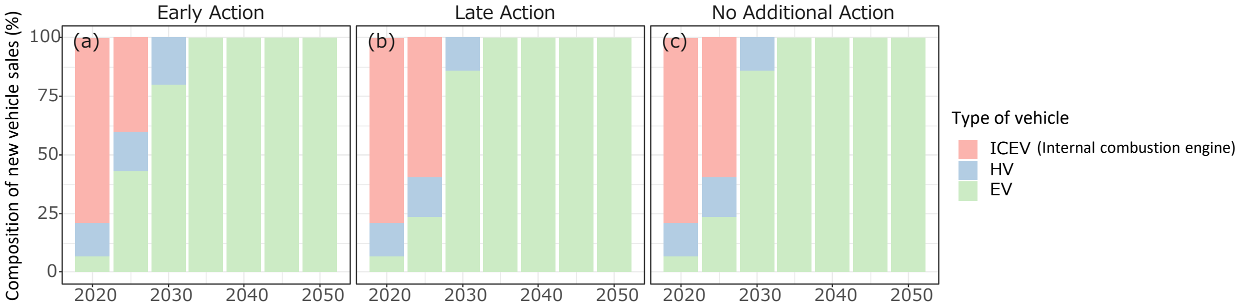

Figure 5.4.2 Changes in the share of newly registered vehicles (U.K.) by type in the CBES scenario

5.5 Chapter Summary

In all of the six cases of analysis examined in this chapter, two to four scenarios were developed based on two or more scenarios provided by the NGFS. If scenarios developed by financial supervisory authorities and central banks are compared with the narratives of the NGFS Scenarios (Phase 2), they can be divided into three categories. The first category comprises scenarios in which transition risk will appear prominently in the future and which were developed in reference to Delayed Transition in the NGFS Scenarios (Phase 2). In Delayed Transition, an emission reduction policy will not be introduced until 2030 and, as a result of quick progress in emission reduction from 2030 onwards, economic losses will be larger than in cases where the transition to a low carbon society will be smooth. The second category comprises scenarios in which physical risk will appear prominently because of total absence of an emission reduction policy and which were developed in reference to Current Policies in the NGFS Scenarios (Phase 2). In many of the cases of risk analysis by financial supervisory authorities and central banks, scenarios that capture the impacts of both transition and physical risks used Net Zero 2050 in the NGFS Scenarios (Phase 2), although this report does not elaborate on this point. The third category comprises scenarios in which both physical and transition risks will be contained to some degree due to a smooth shift to a low-carbon society and which were developed in reference to Net Zero 2050 in the NGFS Scenarios (Phase 2).

In each of the six analyses, single IAM was selected. In the NGFS Scenarios (Phase 2), three IAMs were adopted in order to capture the range of future uncertainties attributable to the quantification. However, at least at the time of authorship of this report, in none of the six cases were multiple IAMs used for analysis out of consideration for future uncertainties. In all European cases (ACPR (2021), ECB (2021), ECB (2022), and BoE (2022)), REMIND-MAgPIE was adopted. On the other hand, a IAM which was not adopted by the NGFS was adopted in the Canadian case (BoC (2022)), while GCAM was adopted in the Australian case (APRA (2021)). One possible reason for this is that which IAM is suited to a certain region depends on such factors as how precise the IAM's economic expressions are or how detailed the regional division is.

Of the many variables calculated under the IAMs in the NGFS scenarios, the carbon price was adopted in most of the six cases of analysis. The carbon price was incorporated into a counterparty-by-counterparty credit risk analysis or into a macroeconomic model as the cost of greenhouse gas emission. However, carbon prices calculated under IAMs are an indicator of the intensity of an emission reduction policy and are determined through a price-setting mechanism and a taxation system different from the ones adopted under actual policy measures, such as carbon taxation and emissions trading.

On the other hand, of the variables of the NGFS scenarios, few other than the carbon price were adopted for analysis. In ECB (2022) and BoE (2022), energy prices (fossil fuel prices and electricity prices) in the NGFS Scenarios (Phase 2) have been provided as variables. However, in both cases, it is unclear to what degree those variables were used for actual risk analysis given that risk measurement was conducted under a bottom-up approach, whereby financial institutions under analysis themselves measured risks.

In many cases, macroeconomic variables were calculated based on carbon prices in the NGFS scenarios using external data and central banks' internal models. In the NGFS Scenarios (Phase 2), some macroeconomic variables were provided by linking the outcomes of the IAMs and climate impact models with NiGEM. However, it is presumed as of the time of authorship of this report that the data for those variables were used in none of the cases.

With respect to some subjects of analysis, variables not included among the variables of the NGFS scenarios were adopted as additional, own variables. Under the IAMs in the NGFS scenarios, there is no report on variables related to the development of individual technologies, except in the energy supply sector. Therefore, in BoE (2022), variables regarding the share of vehicles by type were adopted as additional, own variables in scenarios other than the ones developed based on the NGFS scenarios.

6 Comparison with Japanese Plans Related to Decarbonization

In October 2020, then Prime Minister Suga declared the goal of achieving carbon neutrality by 2050 in a policy speech, and in April 2021, a new emission reduction goal consistent with the 2050 carbon neutrality goal was set. In this chapter, we examine points of attention regarding the challenges for the NGFS Scenarios (Phase 2) and points of attention regarding the analysis of the NGFS scenarios by comparing Japanese plans based on the country's short-term and long-term goals as of the time of authorship of this report with the NGFS scenarios.

6.1 Comparison with Energy Supply and Demand and CO_2 Emission Volume in 2030 Specified in the Sixth Strategic Energy Plan

In light of the goal of achieving carbon neutrality by 2050 (Cabinet decision in October 2020) and the medium-term goal of reducing emissions in FY2030 by 46% while continuing efforts to achieve a higher reduction of 50% (announced in April 2021), in November 2021, a Cabinet decision was made on the Sixth Strategic Energy Plan, which covers energy supply and demand sectors in the period until 2030.[25] This plan has been formulated with the main principle of adopting the viewpoint of S + 3E,[26] which seeks to achieve **e**nergy security, **e**conomic efficiency (low-cost energy supply) and achieve **e**nvironmental integrity with "**s**afety" as the overarching premise and as the top priority. In this section, of the NGFS Scenarios (Phase 2), three scenarios that assume introduction of emission reduction policies with different degrees of ambitiousness (Net Zero 2050 [level of temperature rise: 1.5ºC]; Below 2ºC [level of temperature rise:1.7ºC]; and Current Policies [level of temperature rise: 3ºC+]) are compared with the Sixth Strategic Energy Plan in terms of CO_2 emission volume, electricity generation volume and final energy consumption, among other variables.

6.1.1 CO_2 Emissions (Energy-related Emissions and Electricity-related Emissions in 2030)

Under the Sixth Strategic Energy Plan, energy-related CO_2 emission volume in 2030 is projected to fall to 677Mt-CO_2/year, down 44% compared with 2005 and down 45% compared with 2013, in line with Japan's reduction goal for 2030. Of the energy-related CO_2 emission volume, electricity-related emission volume is projected to fall to 219Mt-CO_2/year, down 50% compared with 2005 and down 62% compared with 2013.

A comparison of those figures with the NGFS scenarios (Phase 2) shows that the emission volumes in 2030 projected under the Sixth Strategic Energy Plan are within the ranges of volumes in Net Zero 2050 and Below 2ºC (Figure 6.1.1 (a)(b)).

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[25] "Cabinet Decision on the Sixth Strategic Energy Plan" (https://www.meti.go.jp/english/press/2021/1022_002.html) (last access: March 22, 2022)

[26] The Sixth Strategic Energy Plan, p.18 (https://www.meti.go.jp/press/2021/10/20211022005/20211022005-1.pdf) (available in Japanese) (last access: March 22, 2022)

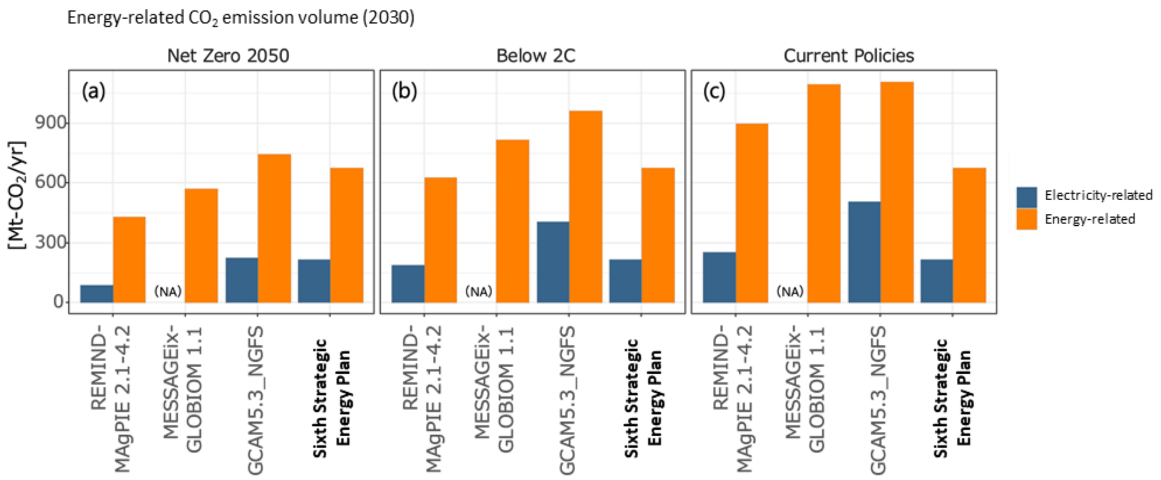

Figure 6.1.1 Comparison of energy-related CO_2 emission volume between the Sixth Strategic Energy Plan and the NGFS scenarios (2030)

6.1.2 Electricity Generation Volume and Non-Fossil Power Source Ratio (2030)

Electricity generation volume in 2030 is projected at 934.0 billion kWh/year (3.36EJ/year) compared with 1,024.0 billion kWh/year in 2013, while the non-fossil fuel power source ratio, which represents the combined share of renewable energy and nuclear power in overall electricity generation, is projected to be raised to around 59%. As a result, electricity-related CO_2 emission volume is projected to be reduced by 62% compared with 2013 (reduced by 50% compared with 2005).

Electricity generation volumes in 2030 projected under the Sixth Strategic Energy Plan are not significantly different from the electricity generation volumes in the NGFS Scenarios (Phase 2) (Figure 6.1.2).

Although there are significant differences in terms of the non-fossil fuel power source ratio across the IAMs in the NGFS Scenarios (Phase 2), the ratios projected under the Sixth Strategic Energy Plan are within the ranges of ratios in Net Zero 2050 and Below 2ºC (Figure 6.1.2 (a)(b)).

While the power source mix varies significantly across the IAMs in the NGFS Scenarios (Phase 2), the variance of the power source mix under the Sixth Strategic Energy Plan is within the range of variance in Net Zero 2050 and Below 2ºC. If examined in more detail, we can see that the volume of electricity generation by coal in 2030 will be almost zero in Net Zero 2050, whereas there will be some volume of residual electricity generation by coal under the Sixth Strategic Energy Plan. On the other hand, the volume of electricity generation by natural gas under the Sixth Strategic Energy Plan will be much smaller than the levels under MESSAGEix-GLOBIOM 1.1 and GCAM 5.3. Meanwhile, although the volume of power generation by nuclear power under the Sixth Strategic Energy Plan will be close to the level under REMIND-MAgPIE 2.1-4.2, it will be much larger than the volumes under MESSAGEix-GLOBIOM 1.1 and GCAM 5.3 (Figure 6.1.2 (a)(b)).

The volume of electricity derived from renewable energy as a whole under the Sixth Strategic Energy Plan will be similar to the level under MESSAGEix-GLOBIOM 1.1 in Net Zero 2050 and Below 2ºC and under GCAM 5.3 in Below 2ºC. On the other hand, it is much smaller than the levels under REMIND-MAgPIE 2.1-4.2 and GCAM 5.3 in Net Zero 2050. However, as mentioned in Section 4.2, under GCAM 5.3, concentrated solar power has a large share in Japan's power source mix (of the 1.23 EJ/year of solar power generation in 2030, CSP will account for 0.478 EJ/year and solar light will make up the remainder). It is difficult to assume that CSP will be introduced on a large scale in Japan, where sunlight volume and the area available for CSP is limited. Indeed, there is no mention of CSP in the Sixth Strategic Energy Plan. The volume of solar power generation in Japan calculated under GCAM 5.3 is presumed to be an overestimation.

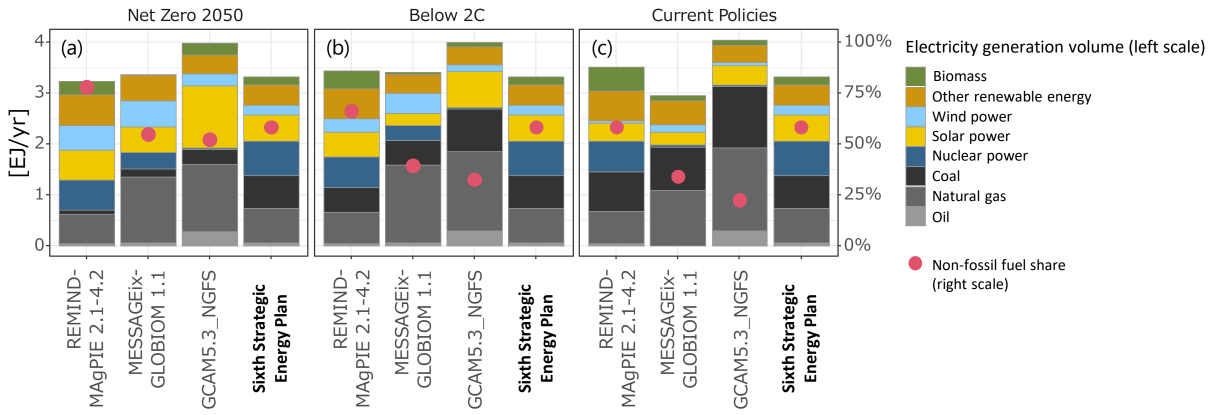

Figure 6.1.2 Comparison of electricity generation volume and non-fossil power source ratio between the Sixth Strategic Energy Plan and the NGFS scenarios (2030)

6.1.3 Final Energy (2030)

Final energy volume is projected to decline from 363 million kL/year (13.9 EJ/year in 2013) in crude oil equivalent in 2013 to 280 million kL/year (10.7 EJ/year) in 2030, with electricity accounting for around 28% of the total and heat, fuels, etc. making up the remainder.

According to a comparison with the NGFS Scenarios (Phase 2), the overall final energy volume and the share of electricity in final energy in 2030 are mostly within the ranges in Net Zero 2050 and Below 2ºC (Figure 6.1.3).

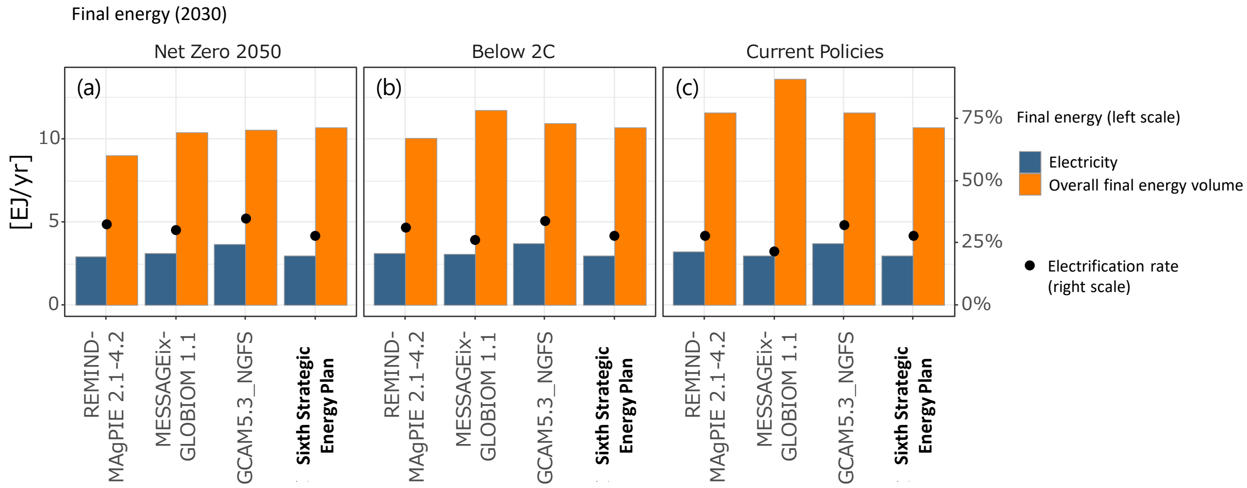

Figure 6.1.3 Comparison of final energy volume between the Sixth Strategic Energy Plan and the NGFS scenarios (2030)

Regarding final energy volume by sector, the volume in the industrial sector is larger and the volume in the transportation is slightly smaller under the Sixth Strategic Energy Plan than in Net Zero 2050 (Figure 6.1.4 (a)).

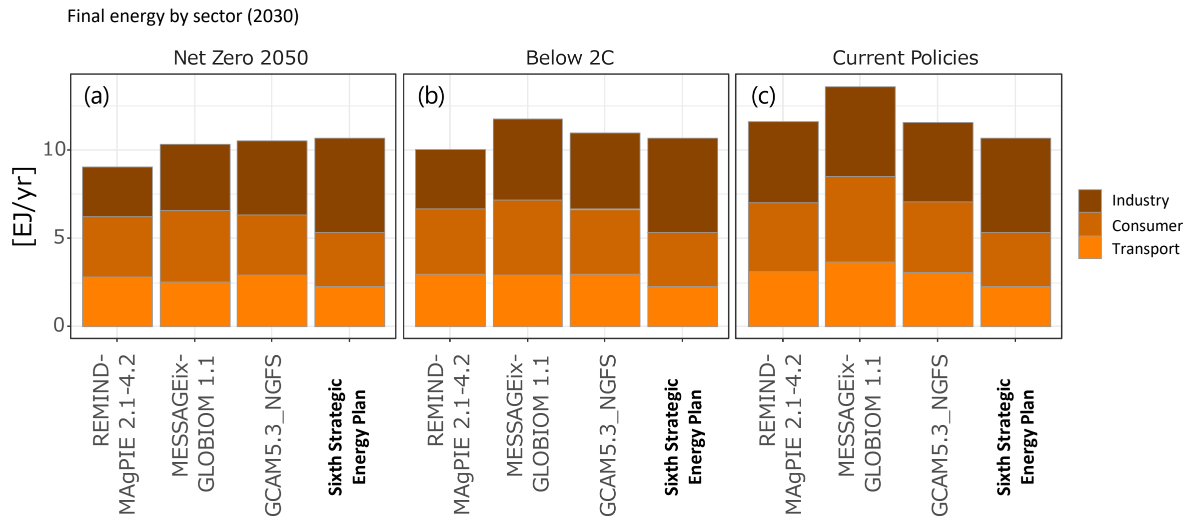

Figure 6.1.4 Comparison of final energy volume by sector between the Sixth Strategic Energy Plan and the NGFS scenarios (2030)

One possible factor behind those divergences is the difference in activity volume in the industrial sector between the NGFS Scenarios (Phase 2) and the Sixth Strategic Energy Plan.

Under the Sixth Strategic Energy Plan, crude steel production volume in Japan in 2030 is assumed to be 90 million tons/year ± approx. 10 million tons. However, in Net Zero 2050 and Below 2ºC in the NGFS Scenarios (Phase 2), crude steel production volume in Japan in 2030 under REMIND-MAgPIE 2.1-4.2 will be much smaller than the estimated volume under the Sixth Strategic Energy Plan, amounting to 64.70 million tons/year in Net Zero 2050 and 70.88 million tons/year in Below 2ºC. On the other hand, crude steel production volume under GCAM 5.3 will be 85.30 million tons/year in Net Zero 2050 and 86.72 million tons/year in Below 2ºC, that is, within the range of "90 million tons/year ± approx. 10 million tons" under the Sixth Strategic Plan (Figure 6.1.5 (a)).[27] As indicated above, under REMIND-MAgPIE 2.1-4.2, crude steel production volume contributes to the difference in final energy consumption.

[27] MESSAGEix-GLOBIOM 1.1 does not provide a report on crude steel production in Japan.

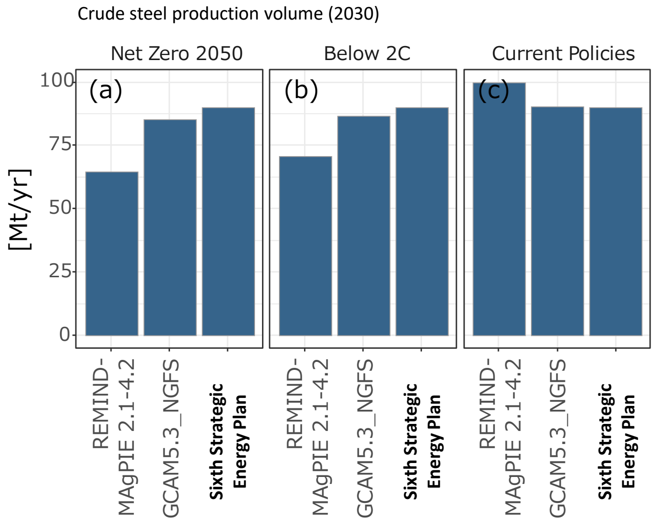

Figure 6.1.5 Comparison of crude steel production volume between the Sixth Strategic Energy Plan and the NGFS scenarios (2030)

When significant differences in the carbon price arise between countries and between regions, a phenomenon called carbon leakage may occur, with production increasing in countries and regions where the carbon price is low and products made there imported into countries and regions where the carbon price is high. However, in Net Zero 2050, worldwide crude steel production will fall steeply from 2020 onwards under REMIND-MAgPIE 2.1-4.2 (Figure 6.1.6), and production volume in Japan is also considered to be affected by that. If we look at the rate of decline in production volume relative to the Current Policies scenario under that premise, there are significant divergences across regions. In Japan's case, the rate of decline is particularly high. Although some correlation can be observed between the rate of decline and the carbon price, it is not necessarily clear (Figure 6.1.7). Before it can be determined that this is an indication of carbon leakage due to a carbon price difference, it is necessary to conduct further examination in light of data to be obtained on yet-to-be-reported import and export volumes.

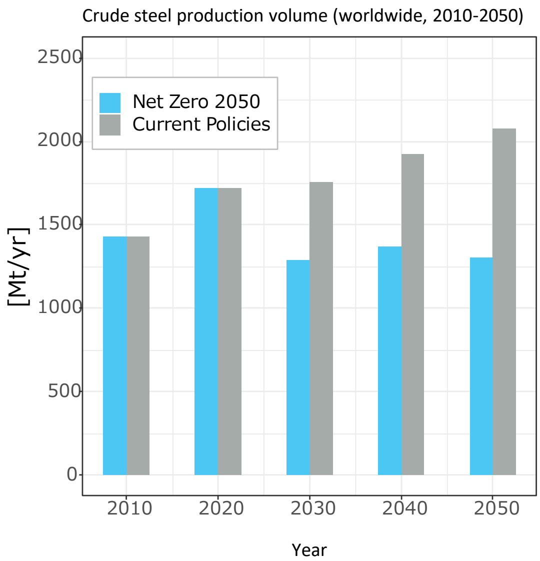

Figure 6.1.6 Changes in worldwide crude steel production volume in the Net Zero 2050 and the Current Policies scenarios under REMIND-MAgPIE 2.1-4.2 (2010-2050)

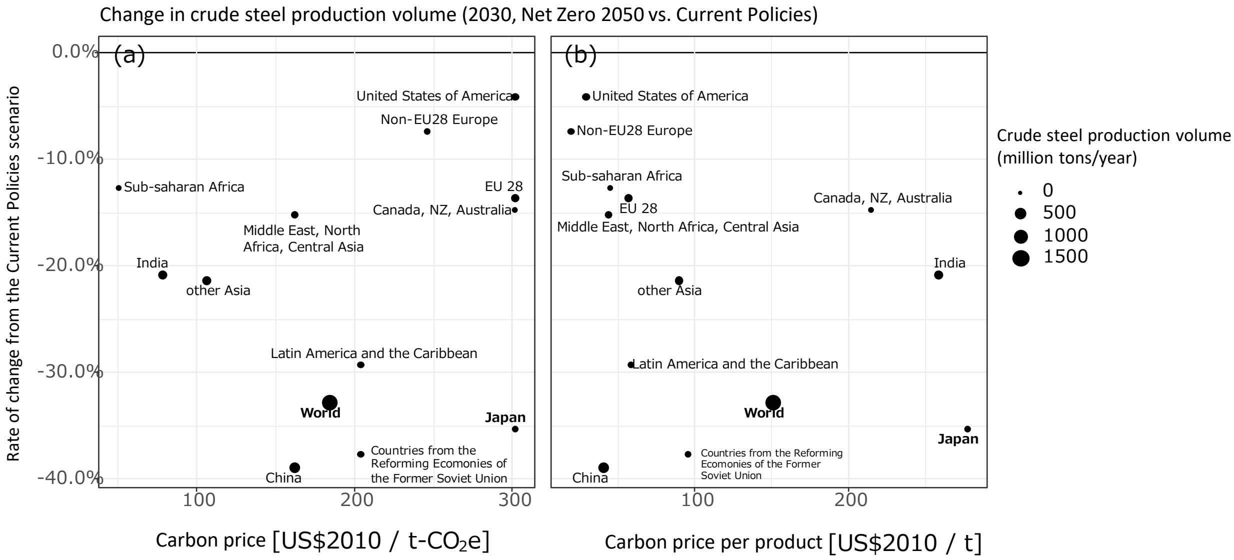

Figure 6.1.7 Impact of (a) carbon price and (b) carbon price per product on the changes in crude steel production volume in Net Zero 2050 relative to Current Policies under REMIND-MAgPIE 2.1-4.2

On the other hand, while energy consumption volume in the industrial sector under GCAM 5.3 is also smaller than the volume under the Sixth Strategic Energy Plan, that is presumed to reflect the effects of the difference in cement production volume. Under the Sixth Strategic Energy Plan, cement production volume in Japan in 2030 is projected at 55.58 million tons/year, against the estimated volumes of 38.20 million tons/year and 44.28 million tons/year in Net Zero 2050 and Below 2ºC, respectively, in the NGFS Scenarios (Phase 2). Cement production volume in 2030 under REMIND-MAgPIE 2.1-4.2 will be 65.31 million tons/year in Net Zero 2050 and 70.43 million tons/year in Below 2ºC, much larger than the estimated volume under the Sixth Strategic Energy Plan (Figure 6.1.8 (a)(b)).

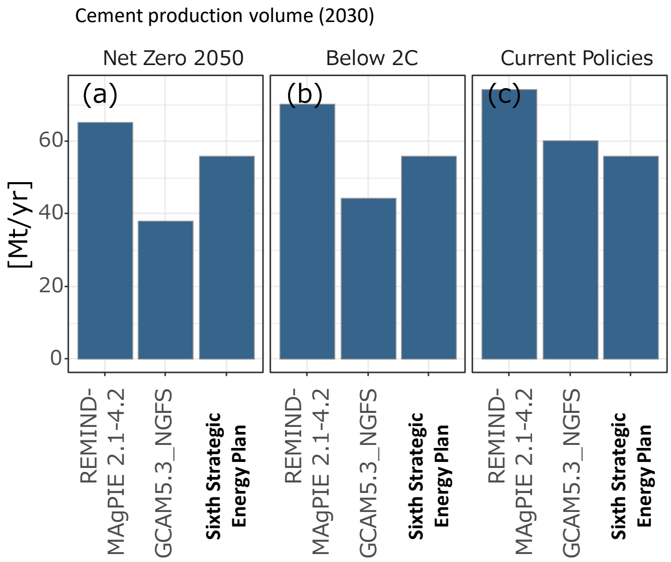

Figure 6.1.8 Comparison of cement production volume between the Sixth Strategic Energy Plan and the NGFS scenarios (Net Zero 2050, Below 2°C, and Current Policies) (2030)

As described above, the comparison between the Sixth Strategic Energy Plan and the NGFS Scenarios (Phase 2) shows that there are some differences in terms of the breakdown of energy supply and consumption by sector even in cases where the CO_2 emission volumes are at a similar level. Those divergences reflect the difference in the estimation approach between the IAMs and the Sixth Strategic Energy Plan. Under the IAMs, the global economy and society as a whole is modeled and many variables are calculated so as to maximize or minimize the value of objective functions under constraining conditions, including CO_2 emission volume. Under the Sixth Strategic Energy Plan, figures for energy supply and demand are calculated individually under the main principle of S + 3E. As a result, even when the emission volume is similar between the IAMs and the Sixth Strategic Energy Plan, the results may vary. The calculation results under the IAMs may be ones that that set back energy security and other objectives, while the cost of emission reduction under the Strategic Energy Plan is not necessarily a minimum one. All the same, the IAMs and the Sixth Energy Plan are mostly consistent with each other in terms of the broad direction.

6.2 NGFS Scenario Variables in High-Emitting Sectors

Under supply and demand estimates under the Sixth Strategic Energy Plan, energy demand assumptions have been made in industrial, residential and commercial, and transport sectors (energy demand sectors), in addition to energy supply assumptions. Table 6.2.1 shows the NGFS scenario variables that correspond to those sectors.

Regarding energy supply sectors (electricity and gas), variables such as facility capacity, electricity generation volume, capital cost and investment value classified by type of generation technology are available. As a result, consistency between investment in specific technologies (e.g., renewable energy electricity generation and fossil fuel electricity generation) and the scenarios can be checked.

On the other hand, as for the industrial sector, data on energy demand and carbon intensity (emission volume per product) is available only with respect to steel, cement, and chemicals. Moreover, there is no data on the breakdown by type of technology within those sectors. Regarding the consumer and transport sectors, there is data only on final energy consumption volume and energy prices. In other words, data used in the NGFS Scenarios (Phase 2) is not detailed with respect to energy demand sectors compared with the data concerning energy supply sectors, so those scenarios provide only a limited set of suggestions regarding specific technologies.

Table 6.2.1 NGFS scenario variables related to the Sixth Strategic Energy Plan

Category	Section	NGFS scenario	
Energy supply	Electricity	Facility capacity (GW) Increase in facility capacity (GW/year)	Biomass (with/without CCS), coal (with/without CCS), gas (with/without CCS), geothermal power, hydro power, nuclear power, oil (with/without CCS), solar light, solar heat, wind power (onshore & offshore), electricity storage
		Electricity generation volume (EJ/year)	Biomass (with/without CCS), coal (with/without CCS), gas (with/without CCS), geothermal power, hydro power, nuclear power, oil (with/without CCS), solar light, solar heat, wind power (onshore & offshore), electricity storage loss, and electricity transmission/distribution loss
		Capital cost (US$2010/kW)	Biomass (with/without CCS), coal (with/without CCS), gas (with/without CCS), geothermal power, hydro power, nuclear power, solar light, solar heat, and wind power (onshore & offshore)
		Carbon capture (MtCO2e/year)	Biomass CCS, and fossil fuel CCS
		Value of investment in electricity generation facilities (billion US$2010/year)	Biomass (with/without CCS), coal (with/without CCS), gas (with/without CCS), geothermal power, hydro power, nuclear power, oil (with/without CCS), solar light, solar heat, wind power (onshore & offshore), electricity storage, and electricity transmission/distribution
		Value of investment in fuel extraction and production (billion US$2010/year)	Biofuels, coal, gas, oil, and uranium
	Gas	Facility capacity (GW)	Biomass (with/without CCS), and coal (with/without CCS)
		Capacity of hydrogen production facilities (GW)	Biomass (with/without CCS), coal (with/without CCS), electrolysis, and gas (with/without CCS)
		Supply volume (EJ/year)	Biogas, coal gas, and natural gas
		Capital cost (US$2010/kW)	Biomass (with/without CCS), and coal (with/without CCS)
		Capital cost of hydrogen production facilities (US$2010/kW)	Biomass (with/without CCS), coal (with/without CCS), electrolysis, and gas (with/without CCS)
		Value of investment in fuel extraction (billion US$2010/year)	Gas
		Value of investment in hydrogen production (billion US$2010/year)	Fossil fuels. Non-fossil fuels, biomass, and renewable fuels
Industrial	Steel	Carbon capture (MtCO2e/year)	Industrial sector as a whole
		Carbon intensity (MtCO2e/Mt)	Overall emission volume, and fuels-derived emissions
		Final energy consumption (EJ/year)	Electricity, gas, heat, liquid fuels, and solid fuels (biofuels and coal)
	Cement	Carbon capture (MtCO2e/year)	Industrial sector as a whole
		Carbon intensity	Manufacturing processes
		Final energy consumption (EJ/year)	Electricity, gas, heat, hydrogen, liquid fuels, and solid fuels
	Chemicals	Carbon capture (MtCO2e/year)	Industrial sector as a whole
		Final energy consumption (EJ/year)	Ammonia, electricity, gas, heat, hydrogen, liquid fuels, and solid fuels
	Oil	Facility capacity (GW)	Biomass (with/without CCS), coal (with/without CCS), and gas (with/without CCS), and oil
		Capital cost (US$2010/kW)	Biomass (with/without CCS), coal (with/without CCS), gas (with/without CCS), and oil
		Value of investment in fuel extraction (billion US$2010/year)	Oil
		Value of investment in fuel refining (billion US$2010/year)	Biomass, coal, gas, and oil
Non-industrial	Residential and commercial	Final energy consumption (EJ/year)	Electricity, gas, heat, liquid fuels, solid fuels (biofuels and coal), hydrogen, and air conditioning
		Energy prices (US$2010/GJ)	Electricity, gas, heat, liquid fuels, and solid fuels
Transport	Passengers	Final energy consumption (EJ/year)	Electricity, gas, heat, hydrogen, and liquid fuels
	Freights	Final energy consumption (EJ/year)	Electricity, gas, heat, and liquid fuels
	-	Energy prices (US$2010/GJ)	Hydrogen and liquid fuels

7 Conclusion

7.1 Climate-related Financial Risk Analysis and NGFS Scenario's Contributions

One motivation behind the development of the NGFS scenarios is to support climate-related financial risk analysis by financial supervisors, central banks and financial institutions by providing common scenarios with high reliability and comparability (NGFS, 2021b).

This report focused attention on the key variables of the NGFS Scenarios (Phase 2) and conducted detailed analysis with respect to each of the entire world (Section 4.1), Japan (Section 4.2) and major regions around the world (Section 4.3). As a result, it has been found that in the NGFS Scenarios (Phase 2), six scenarios with different assumptions concerning the ambition of emission reduction policy and future technology developments have been set and that with respect to each scenario, changes in variables such as future CO_2 emission volume, energy supply, energy demand by sector and capacity of emission reduction technology introduced have been quantitatively expressed. In addition, in the NGFS Scenarios (Phase 2), the outcomes of the IAMs that quantify variables related to transition risk are linked with climate models, climate impact models, and macroeconomic models in multiple phases, and as a result, the outcomes of those models are consistent within each scenario, although that point was not covered by the analysis in this report.

Moreover, it has been confirmed that many key variables calculated under the IAMs in the NGFS Scenarios (Phase 2) are consistent with existing scenarios developed based on the results of climate science as of now except regarding the points to be mentioned in Section 7.2 (Section 4.4). The NGFS Scenarios (Phase 2) ensure that the calculated values of the variables are within ranges considered to be appropriate in light of future uncertainties by quantifying the narrative of each scenario under the three IAMs so as to afford some flexibility to the scenarios. Although it should be kept in mind that the presence of consistency with existing climate-related scenarios does not guarantee the accuracy of future forecasts, it provides a certain level of validity to the quantification results in the NGFS Scenarios (Phase 2).

From the abovementioned findings, it can be said that the development and publication of the NGFS Scenarios (Phase 2) has made it possible to measure the impact of transition and physical risks on the soundness of financial institutions and financial systems in major regions around the world under the same preconditions. Previously, in risk analysis in the climate science field, it was common to use a combination of different scenarios depending on the analysis subject or the region even in cases where introduction of an emission reduction policy with the same level of ambitiousness is assumed (TCFD, 2020). The development of common scenarios by the NGFS is expected to improve comparability in climate-related financial analysis and the quality of financial risk analysis by financial supervisory authorities and central banks.

Moreover, as a result of sorting and analyzing example cases of use of the NGFS scenarios by financial supervisory authorities and central banks, it has become clear that there is a certain level of commonality in terms of the types of scenarios and variables used for analysis (Chapter 5). As climate-related financial risk analysis is still a new field, there is no established analysis approach at the moment. Therefore, the NGFS has published scenarios that assume various analysis approaches while encouraging the sharing of cases among financial supervisory authorities and central banks (NGFS, 2020; NGFS, 2021c). Although it is unclear to what degree the analysis approaches adopted by various financial supervisory authorities and central banks will converge, it may be said that the NGFS scenarios have played an important role as the basis for encouraging the sharing of knowledge obtained in various countries.

7.2 Notes and Proposals concerning Climate-related Financial Risk Analysis in Japan

Chapter 4 sorted the characteristics of the key variables of each scenario and IAM and mentioned some points of attention concerning analysis. Chapter 5 focused attention on example cases of climate stress tests conducted by financial supervisory authorities and central banks and sorted usage of the NGFS scenarios in financial risk analysis. Chapter 6 considered the sufficiency and usefulness of the NGFS Scenarios (Phase 2) through comparison with Japan's Strategic Energy Plan. This section cites possible points of attention useful for climate-related financial risk analysis to be conducted in Japan in the present and future to the NGFS proposals for improvement and correction.

7.2.1 Carbon Prices

In the NGFS Scenarios (Phase 2), the impact on macroeconomic variables is calculated using carbon prices calculated under IAMs. In all cases of use of the NGFS scenarios by foreign financial supervisory authorities and central banks, transition risk is measured by using carbon prices calculated under the IAMs adopted in those scenarios. From this, it can be said that carbon prices calculated under IAMs represent the most important variable in analysis of transition risk based on the NGFS scenarios.

In NGFS scenarios (Phase 2) that assume introduction of ambitious emission reduction policies, the carbon price in 2030 is projected to rise to a range of \$96.8/t-CO_2 to \$197.7/t-CO_2 and the carbon price in 2050 is projected to rise to a range of \$486.2/t-CO_2 to \$672.7/t-CO_2 (both figures represent the worldwide average in terms of the 2010 dollar in Net Zero 2050), and the rate of price rise in advanced economies is higher than the worldwide average. On the other hand, it has become clear that there are divergences in the carbon price across the IAMs within the same scenario. The carbon price is endogenously determined as a shadow price within each IAM. It is presumed that in principle, there is a one-to-one correspondence between emission reduction and time-sequential change in the carbon price.

On the other hand, in the WEO-2021, the carbon price is exogenously set according to the national policy and commitments regarding carbon pricing and the degree of emission reduction in each scenario. In a scenario that corresponds to Net Zero 2050, the carbon price in 2050 will vary depending on the region—in the range of \$160/t-$CO_2$to \$200/t-CO_2 (APS), in the range of \$55/t-CO_2 to \$250/t-CO_2 (NZE) (both figures are in terms of the 2020 U.S. dollar[28])—and will be much lower than the levels in the NGFS Scenarios (Phase 2). The disparities are attributable to the differences between the NGFS scenarios and the WEO-2021 in terms of the approach to carbon price determination, fossil fuel prices and technology cost. Carbon prices calculated under the IAMs in the NGFS Scenarios (Phase 2) are determined during the process whereby prescribed volume emission reduction is achieved based on idealized (simplified) energy and economic assumptions under the valuation approach prescribed by each IAM (optimization; see Box 1). On the other hand, in the scenarios of the WEO 2021, in addition to carbon pricing, a broad range of other policy measures that may contribute to emission reduction is taken into consideration, and the carbon price is not a marginal reduction cost that is obtained through optimization calculation. As explained above, carbon prices that are linked to emission reduction through the formularization under the IAMs and carbon prices that are set in a situation where policy measures other than carbon pricing exist are different in nature. Generally speaking, the former case of carbon prices is higher than the latter case and

[28] If the figures are converted from US\$2020 terms to US\$2010 using a deflator (e.g., https://data.worldbank.org/indicator/NY.GDP.DEFL.ZS?locations=US), they decrease by 15%.

depends heavily on the formularization under IAMs.

When using carbon prices calculated under IAMs in transition risk analysis, it is necessary to keep in mind that those prices are different in nature from carbon prices in the real world, where policy measures other than carbon pricing may contribute to emission reduction.

7.2.2 Energy Prices

Fossil fuels (primary energy)

There are disparities across the IAMs in terms of fossil fuels (primary energy), with extreme price changes observed in some cases. Fossil fuel prices calculated under IAMs (REMIND-MAgPIE 2.1-4.2 and MESSAGEix-GLOBIOM 1.1 in the case of the NGFS Scenarios (Phase 2)) reflect the dynamics of the oil and gas market in a state of long-term equilibrium, so they are calculated under an approach disconnected from the mechanism that determines prices in the real world. Under this calculation approach, factors such as the resource supply cost, fuel demand, and climate policy affect prices through the objective function regarding the object of optimization under the IAM. The wide range of changes in fossil fuel prices indicate that the degree of future uncertainty is high. On the other hand, as fuel prices affect important macroeconomic variables such as the inflation rate, it is useful to ensure that the factors of changes can be examined by increasing the transparency of assumptions, including extraction cost and the amount of recoverable reserves.

In addition, because of considerable differences across the IAMs in terms of the period of actual data incorporated into the model used for estimating future pathways, there are large divergences between the IAMs in terms of fossil fuel prices (gas and oil prices in particular) at the most recent point in time (2020). The divergences between the IAMs in terms of energy prices are also large compared with differences in the values of other variables in 2020. As a result, it is becoming increasingly difficult to conduct price comparison between models in terms of absolute value (see Sections 4.1.9 and 4.2.9), so this report conducted inter-model comparison in terms of the rate of change compared with 2020. When using data provided by the NGFS in financial risk analysis, it may also become necessary to conduct comparison in terms of the rate of change compared with 2020, rather than in terms of absolute value. In principle, it is desirable to first align the period of actual data and set the base year under each IAM at the most recent year and then ensure to some degree, consistency with actual prices at the moment.

Under MESSAGEix-GLOBIOM 1.1, the values reported with respect to Japan are downscaled figures, while universal energy prices are applied within each region. When conducting analysis concerning Japan, it should be kept in mind that the values under MESSAGEix-GLOBIOM 1.1 have not been adjusted to reflect factors specific to Japan.

It has also been found that fuel prices adopted for climate change stress tests conducted by financial supervisory authorities and central banks are determined based not only on the NGFS scenarios but also on external data and variables which were not derived from the NGFS. It is desirable to identify the factors that lead to the use of external data and in-house calculations and to make improvements so that those factors can be taken care of within IAMs.

Electricity price (secondary energy)

It has been found that in some scenarios which assume introduction of ambitious emission reduction policies, the electricity price (secondary energy) under REMIND-MAgPIE 2.1-4.2 will show an extreme rise, followed by a steep fall (see Sections 4.1.9 and 4.2.9). This trend will be more prominent in Japan in particular than on a worldwide basis. As in the case of primary energy, secondary energy prices under IAMs are calculated under an approach disconnected from the mechanism that determines prices in the real world. Under REMIND-MAgPIE 2.1-4.2, the electricity price is determined under a relational expression between changes in the electricity supply-demand balance and in the elements of the income identity. The elements of the income identity include the value of investment in power sources and electricity transmission and distribution and fossil fuel costs. As the timing of expansion in investment in low-carbon power sources coincides with the timing of price increase, a temporary increase in related capital investment may affect the income identity. On the other hand, it has been reported that the electricity price in Japan under MESSAGEix-GLOBIOM 1.1 will also rise significantly in scenarios which assume introduction of an ambitious emission reduction policy (*there has been no report on worldwide data). However, there will be no steep peak unlike in the case of REMIND-MAgPIE 2.1-4.2 and the price will remain high between 2030 and 2050 although there are disparities across the scenarios. This is presumably because the impact of capital investment on price determination is not so direct as in the case of REMIND-MAgPIE 2.1-4.2. However, it should be kept in mind that energy prices under MESSAGEix-GLOBIOM 1.1 have not been downscaled specifically for Japan. Under GCAM5.3, prices are calculated so as to balance supply and demand in region-by-region and sector-by-sector markets without relying on perfect foresight, so significant price changes are unlikely to occur.

As explained above, the price-determination mechanism varies across the IAMs, and analysts must keep the difference in the mechanism in mind when using electricity prices calculated under the IAMs.

As in the case of fossil fuel prices, there are significant differences across the IAMs in terms of the electricity price in 2020. Therefore, when using data provided by the NGFS in financial risk analysis, it may become necessary to use the rate of change compared with 2020, rather than the absolute value of price.

Among the example cases of analysis by financial supervisory authorities and central banks, in the ECB's SSM Stress Test 2022, the NGSF Scenarios (Phase 2) were used and the electricity price calculated under REMIND-MAgPIE 2.1-4.2 was adopted without any adjustment (ECB, 2021).

7.2.3 Energy Demand Sectors

In the NGFS Scenarios (Phase 2), emission volume and production volume in major sectors were calculated with respect to each of the industrial, consumer and transport sectors. Those data are essential for verifying consistency between the existing pathways and the scenarios in sector-by-sector analysis. However, the number of variables regarding energy demand sectors is smaller than the numbers of variables regarding fossil fuel demand and energy supply and breakdowns of data by type of technology are not detailed.

Industrial sectors

The NGFS Scenarios (Phase 2) incorporated data on emission sectors that are major CO_2 emitters, such as "steel," "cement" and "chemicals," but there are only a very few variables that can be used for analysis, including the carbon intensity of products and production volume. In the case of "steel," for example, there is not information on the breakdown by type of furnace (blast furnace or electric arc furnace), CCS capacity introduced for blast furnaces, the value of investment in low-emission technology, or import/export volume. With respect to major segments of the industrial sector, it is desirable to provide more precise information by adopting more variables and by providing more detailed breakdowns by type of technology so that analysts can examine transition pathways in detail based on scenarios.

The comparison between the NGFS Scenarios (Phase 2) and Japan's emission reduction policy showed that there are significant differences between the assumptions of Net Zero 2050 and Japan's Sixth Strategic Energy Plan in terms of crude steel production volume and cement production volume. One possible factor behind the differences may be the impact of carbon pricing in the NGFS scenarios, but it is difficult to verify this conjecture based on figures reported by the NGFS alone. With respect to major segments of the industrial sector, it is necessary to verify the basis for calculating production volume (activity volume) and the validity of calculated values in light of import/export volumes.

Production volume may change significantly depending on the nature of a border carbon adjustment mechanism, which may be used in conjunction with carbon pricing. Currently, the EU is considering introduction of a carbon border adjustment mechanism that is linked to the EU Emission Trading System (EU ETS). Therefore, when conducting analysis using IAMs in the future, it is desirable to incorporate carbon border adjustment into models in a way that reflects developments in the real world.

Non-industrial sectors

While there are reports on such variables as CO_2 emission volume and energy demand in the consumer and transport sectors in the NGFS Scenarios (Phase 2), the number of variables is limited and detailed breakdowns of data by type of technology are unavailable, as in the case of the industrial sector. Although one possible option is adopting a wider variety of variables within the IAMs, analysts should consider using external data and models as a complementary measure in order to obtain necessary information. Among the example cases of analysis by financial supervisory authorities and central banks, BoE (2021) of the United Kingdom adopted the share in new vehicle sales by type of vehicle as a complementary variable (BoE, 2021).

Under IAMs, economic, social and technological changes are supposed to be expressed with consistency under greenhouse gas emission constraints, but the more complex the model is, the more difficult the calculations are. The NGFS is expected not only to improve its IAMs but also to provide guidelines for approaches to complementing the IAMs and present example cases.

7.2.4 Integration of New Technology and Scientific Knowledge

The NGFS plans to periodically update the scenarios, so it is expected to reflect technological advances and the most advanced climate science knowledge in the updated scenarios.

One of the important climate mitigation technologies that have not been reflected in the NGFS Scenarios (Phase 2) is Direct Air Carbon Capture and Storage (DACCS). The NGFS Scenarios (Phase 2) incorporated biomass-based CCS (BECCS) and afforestation as CO_2 removal technologies, but the capacity of both these technologies introduced will be limited due to land use constraints. Although DACCS is subject to cost and energy demand constraints, it could change the balance between CO_2 emission reduction and CO_2 removal.

The IPCC Sixth Assessment Report (IPCC AR6) has been published in 2021 through 2022. In the report, the relationship between CO_2 emission volume and temperature rise has been updated based on the most advanced climate science knowledge. It is desirable for the NGFS scenarios to be integrated with the most advanced scientific knowledge to the maximum possible extent.

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