Systems Analysis Group

Members (As of Apr. 2024)

Keigo Akimoto, Group Leader, Chief Researcher
Koya Yamada, Associate Chief Researcher
Kenichi Wada, Senior Researcher
Miyuki Nagashima, Senior Researcher
Takashi Homma, Senior Researcher
Fuminori Sano, Senior Researcher
Ayami Hayashi, Senior Researcher
Atsuko Fushimi, Senior Researcher
Noritaka Mochizuki, Senior Researcher (concurrent)
Tadashi Kuwatsuru, Senior Researcher
Yuko Nakano, Senior Researcher
Naoko Onishi, Senior Researcher
Teruko Hashimoto, Senior Researcher
Hitotsugu Masuda, Researcher
Teruhisa Ando, Researcher
Jubair Sieed, Researcher
Dahyun Kang, Researcher
Kiyomi Yamamoto, Assistant Researcher
Misako Saito, Assistant Researcher
Sachiko Kudo, Assistant Researcher
Ryoko Minamimura, Assistant Researcher

Research Activities in Systems Analysis Group

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

Achieving the long-term 2°C or 1.5°C goals of the Paris Agreement is required. However, it is said that there is a large emissions gap between the current situation or the emission reduction targets submitted by each country in their Nationally Determined Contributions (NDCs) for 2030 and those long-term goals. It is important to present emission pathways and countermeasure scenarios for each sector quantitatively and consistently to limit temperature rise below 2°C or even 1.5°C, including transition periods such as 2030 and 2040. With this background, in FY2023, we have developed sectoral transition roadmaps for the world and Japan to achieve the 2°C and 1.5°C goals using the global energy and climate change mitigation assessment model DNE21+, which is published on the RITE website[1]. This report provides an overview of the analyses.

1. Development of long-term scenarios towards Carbon Neutrality (CN) and scenario assumptions

1.1. Background of developing transition roadmaps

It is necessary to strengthen measures in each sector to achieve the 2°C and 1.5°C long-term goals of the Paris Agreement and carbon neutrality (CN) early in the second half of the 21st century. Various possibilities have been presented such as in the IPCC AR6[2], including scenarios with high reliance on negative emissions through carbon dioxide removal (CDR) and scenarios with low reliance on negative emissions through the realization of a low energy demand society. Furthermore, transition pathways to CN realization are even more varied. For instance, emission reduction pathways for each industrial sector differ from sector to sector in terms of the lifetime of existing infrastructure and the difficulty of emission reduction measures. Uniform reductions may increase the cost of countermeasures and make emission reductions more difficult.

However, in the case where countries, industries, and companies take emission reduction measures at a slower rate than others, there is also a risk of being criticized as "greenwashing". On the other hand, financial institutions and evaluation agencies do not necessarily have a sufficient understanding of the pathways for emission reductions that are consistent with the energy system as a whole, so quantitative information to make judgments about the appropriateness of investments is needed. Therefore, the Network for Greening the Financial System (NGFS) and other organizations are developing emission reduction scenarios using integrated assessment models that enable quantitative analysis[3]. On the other hand, these do not provide sufficient information on sectoral emission reduction pathways. The International Energy Agency (IEA) has also presented, but not enough information by country, especially for the 1.5°C scenario. Likewise, the report by the International Capital Market Association (ICMA)[4] also has issues regarding the consideration of regional and industrial characteristics. The Government of Japan has developed a transition roadmap for FY2021-22 to provide a specific direction for the transition toward achieving carbon neutrality, and to use this roadmap in transition finance. These also provide useful information, but at the same time, they were developed on a sector-by-sector basis, therefore, there is a need to further improve the accountability for consistency with the overall 2°C and 1.5°C emission reduction pathways, as well as consistency among sectors.

Therefore, we developed emission reduction scenarios, including transition roadmaps by sector, that are consistent with the 2°C and 1.5°C targets globally and with economic rationality while taking into account the differences among countries and sectors, using the global energy and climate change mitigation model: the DNE21+ model, which minimizes total energy systems costs for the period up to 2100.

1.2. Scenrio assumptions

For assuming scenarios for quantitative analyses using DNE21+, the NGFS scenarios[3] are basically referenced. NGFS develops Orderly scenarios and Disorderly scenarios, based on whether the transition will proceed orderly or not. Complying with this, we have developed our Orderly scenarios and Disorderly scenarios, as well as an additional scenario similar to Net Zero by 2050 (NZE)[5] by IEA. Outlines of the scenarios and assumptions for model analyses with the DNE21+ are shown in Table 1. In terms of temperature rises, two scenarios that are consistent with a 2°C target, and three scenarios consistent with a 1.5°C target are assumed. Global CO_2 emissions scenarios are assumed as shown in Figure 1.

Table 1 Assumed scenarios (outline)

Scenarios	Global average temp. increase	Policy speed#	CDR contribution	Renewables and BEV	Differences in policy intensity among regions	Relation to other scenarios		
						IPCC AR6 (IPCC 2022)	NGFS (2022)	IEA
Disorderly Below 2 °C	1.7 °C in 2100 (peak:1.8 °C)	Gradual (NDCs in 2030)	medium	Medium cost reductions	Large (major developed countries: CN by 2050)	Likely below 2 C, NDC [C3b]	Disorderly: Delayed Transition	APS (WEO 2022)
Orderly Below 2 °C	1.7 °C	Rapid	Small	High cost reductions	Small (equal MAC among countries)	Likely below 2 C with immediate action [C3a]	Orderly: Below 2C	SDS (WEO 2021)
Disorderly 1.5 °C	1.4 °C in 2100 (peak:1.7 °C)	Gradual (NDCs in 2030)	Large	Medium cost reductions	Large (major developed countries: CN by 2050)	1.5 C with high overshoot (IMP-Neg) [C2]	(Disorderly: Divergent Net Zero)*	
Orderly 1.5 °C	1.4 °C in 2100 (peak:1.6 °C)	Rapid	Medium	High cost reductions	Medium (major developed countries: CN by 2050)	1.5 C with no or limited overshoot [C1]	Orderly: Net Zero2050	
1.5C-CO2_CN	Approx. below 1.5 °C	Rapid	Small (Near-zero of CO_2 by sector)	High cost reductions	Large (major developed countries: CN by 2050)	1.5 C with no or limited overshoot [C1]		NZE

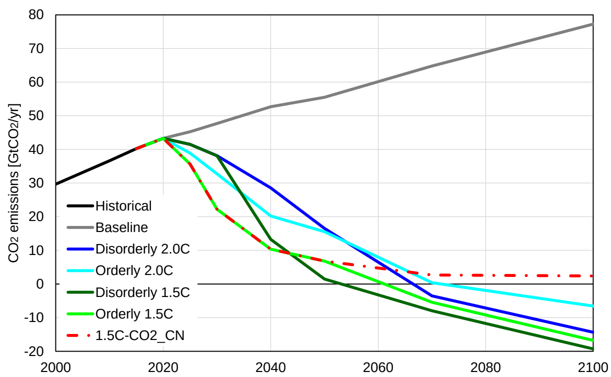


Figure 1 Global CO_2 emissions pathways

2. World

2.1. Scenario analysis using DNE21+

This section describes the scenarios for the world.

Figure 2 shows the global GHG emissions by sector. Earlier CO_2 reduction from the power generation sector is shown to be economically rational compared to other sectors.

Figure 3 shows the global electricity supply. While coal power generation is significantly suppressed even in 2030, several scenarios can be seen where gas power generation with CCS increases more than in the baseline, indicating the transition to gas is proceeding. For Orderly scenarios where relatively lower expansion rates of CO_2 storage are assumed, the introduction of gas power with CCS is smaller compared to Disorderly scenarios, and solar photovoltaics (PV) and wind power with further cost reduction assumed will increase instead.

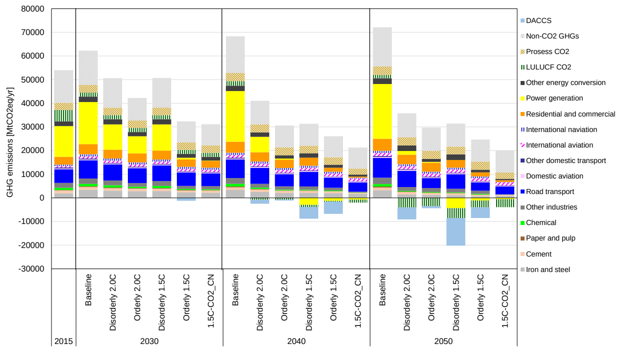


Figure 2 GHG emissions (world)

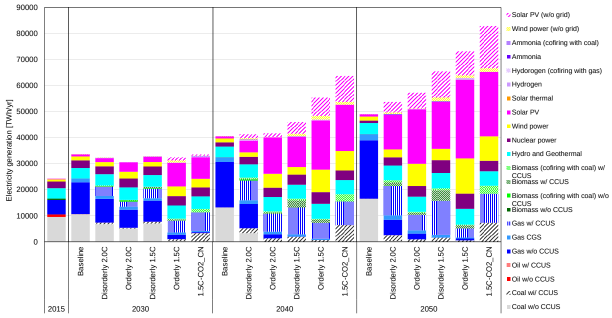


Figure 3 Electricity supply (world)

Figure 4 shows the global final energy consumption in the industry sector. Similar to the power generation sector, coal consumption decreases, and consumption of gas and electricity increases. The decrease in coal consumption is relatively smaller compared to the power generation sector because coal usage is needed for crude steel production by the blast furnace/basic oxygen furnace (BF-BOF) in the iron and steel sector. Compared to the analysis results for Japan shown later, consumption of hydrogen, ammonia, and synthetic methane (e-methane) is relatively smaller as many countries have larger potentials for domestic renewable energies, renewable energies over cross-border interconnection, and domestic CO_2 storage. However, in the 1.5C-CO_2_CN scenario where large deployments of CDR are constrained, those consumption is substantial.

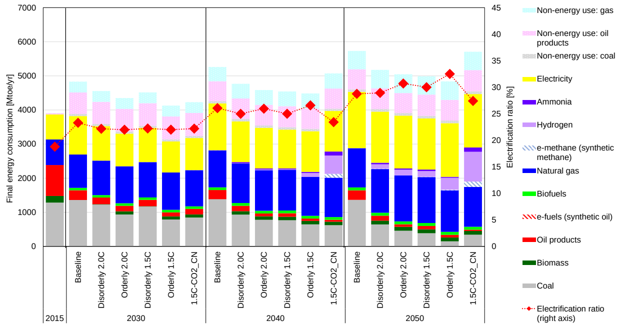


Figure 4 Final energy consumption in industry (world)

2.2 Comparison with other scenarios

Comparisons with existing international scenario analyses are described below. As described below, scenario analyses by RITE are highly consistent with them and have high explainability, with small variations due to the differences in models and assumptions.

Figure 5 shows the comparison of global CO_2 emissions by sector with those by IPCC. The sectoral CO_2 emissions in DNE21+ scenario analyses are almost consistent with those in IPCC and encompass their upper and lower limits, with a few exceptions of exceeding their ranges in the transport and the residential and commercial sectors. A major factor of residual emissions in these sectors slightly exceeding IPCC scenario ranges may be whether CDRs, especially direct air carbon capture and storage (DACCS) are considered in the models or not (Figure 6).

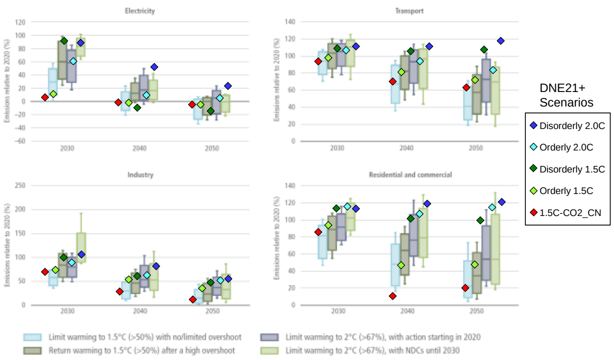


Figure 5 Comparison with global CO_2 emission scenarios of IPCC

Source) IPCC AR6[2], with DNE21+ scenarios plotted
Note) Boxes indicate 25th and 75th percentiles, while whiskers indicate 5th and 95th percentiles in IPCC scenarios.

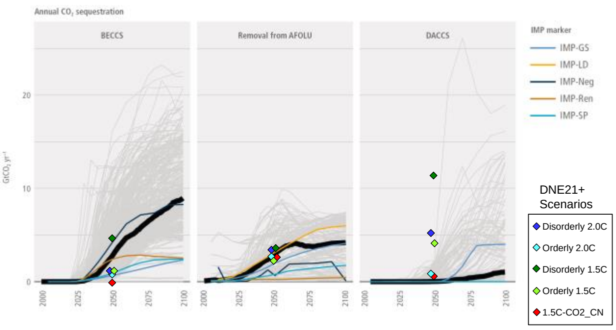


Figure 6 Comparison with global CDR scenarios of IPCC

Source) IPCC AR6[2], with DNE21+ scenarios plotted (only for 2050)
Note) As for IPCC AR6, only the scenarios categorized as C1-C3 are shown.

Figure 7 shows a comparison with NGFS in carbon prices (CO_2 marginal abatement costs; MAC) in each scenario. For 1.5°C scenarios, carbon price levels in DNE21+ scenarios are almost consistent with those in NGFS scenarios, with a tendency of slightly lower MAC as DACCS are considered in the DNE21+ model. Comparisons of MACs with scenarios in the IPCC report are shown in Figure 8. Many models in the IPCC report estimate them under the condition of MACs being globally equalized. MACs in DNE21+ scenarios are consistent with those in the IPCC report. While many IPCC scenarios do not assume DACCS, DNE21+ does assume DACCS, thus leading to slightly lower MACs in 2050 compared to those in the C1 scenario in IPCC.

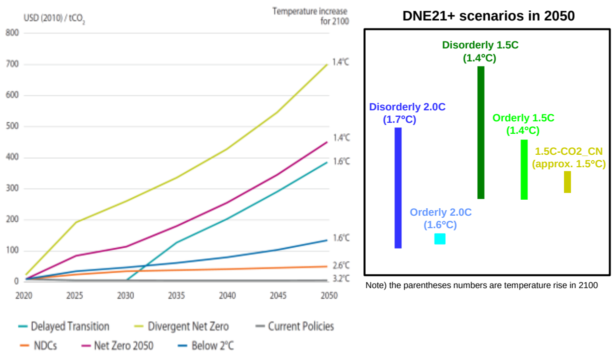
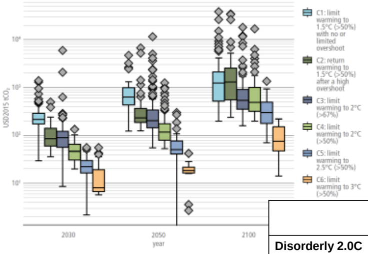


Figure 7 CO_2 marginal abatement costs: compared with NGFS



	DNE21+	IPCC (25-75 percentile, approx.)	
Disorderly 2.0C	119～500	C3	150～350
Orderly 2.0C	158	C3	
Disorderly 1.5C	268～685	C2	200～350
Orderly 1.5C	268～465	C1	450～1000
1.5C-CO2_CN	293～351	C1	

Figure 8 CO_2 marginal abatement costs: compared with IPCC

3. Japan

This section describes the quantitative scenario analysis for Japan.

3.1. GHG emissions

Figure 9 shows Japan's GHG emissions by sector. For three scenarios where net-zero emissions of GHG are achieved by 2050 (Disorderly 2.0C and Disorderly/Orderly 1.5C), measures such as DACCS, land-use CO_2 (CO_2 sequestration by afforestation), and net negative emissions of CO_2 in the power sector (achieved with biomass with CCS (BECCS) and e-methane with CCS) are introduced. For the Orderly 2.0C scenario where net-zero emission of GHG by 2050 is not assumed and global cost minimization (equal MACs across countries) is assumed, a reduction of approximately 70% compared to

2013 is shown to be cost-efficient. In this case, residual CO_2 emissions from the power sector or iron and steel sector are allowed.

Figure 10 shows the balance between CO_2 capture and storage/utilization in Japan. In 2030 and 2040, CO_2 captures from coal and gas power plants or BF-BOF are introduced. For some scenarios, captures from biomass power plants and DAC are introduced in 2040 and their amount increases in 2050. In the 1.5-CO_2_CN scenario, BECCS and e-methane with CCS in the power sector, and DACCS are not allowed (CCU that utilizes CO_2 captured by DAC is allowed), therefore CO_2 captures from coal (including biomass co-firing) and gas power plants and cement sector are observed even in 2050.

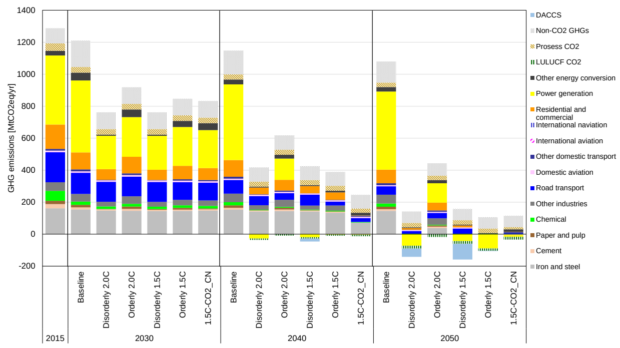


Figure 9 GHG emissions (Japan)

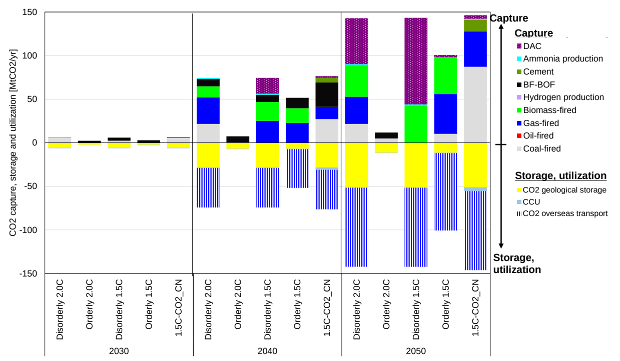


Figure 10 CO_2 balance (Japan)

3.2. Primary energy supply, electricity, and other energy conversion

Figure 11 shows the primary energy supply in Japan. Japan's potential for renewable energy and CO_2 sequestration is not large compared to its energy demand, therefore, importing and using carbon-neutral fuels such as e-methane, e-fuels, and biofuels as well as hydrogen and ammonia are evaluated as cost-effective. In Orderly 2.0C with emission reductions of around 70% below 2013 levels by 2050, those amounts are relatively small, and it is overall cost-effective to deepen emission reductions in other countries to achieve the global 2°C target, leaving coal and gas supplies without CCS.

Figure 12 shows the amount of electricity generated. To promote electrification, the total amount of electricity generated increases, especially under the severe emission reduction scenario. In addition to expansions of renewable energy sources (e.g., solar PV) and utilization of CCS, power generation using imported hydrogen and ammonia is being promoted to reduce CO_2 emissions. It is noted, e-methane is used for gas power generation with CCS in 2050 in all scenarios except Orderly 2.0C and 1.5C-CO_2_CN. In the Disorderly scenarios, since variable renewable energy (VRE) is assumed to be relatively high, imported from overseas hydrogen and ammonia (since a high rate of expansion of CO_2 storage is assumed, it is easier to produce blue hydrogen and blue ammonia abroad) tend to be used for power generation. On the other hand, in the Orderly scenarios, the use of VRE, which is expected to become even cheaper, is relatively expanded, while power generation using hydrogen and ammonia is rarely seen. The latter is because the expansion rate of CO_2 sequestration is assumed to be low, making production overseas difficult. Note that 1.5C-CO_2_CN constrains the use of BECCS and e-methane with CCS to be unavailable, resulting in the deployment of coal power with CCS.

Figure 13 shows the CO_2 emission intensity in the power sector for each scenario. Although the power source composition is different in Disorderly 2.0C/1.5C and Orderly 1.5C as mentioned above, there is no significant difference in the transition of the CO_2 emission intensity, and it is evaluated to be cost-effective overall to achieve net zero GHG emissions around 2040 in the power sector.

Figure 14 shows a comparison of the cumulative CO_2 emissions in the power sector for 2020-2030 with the Government of Japan Roadmap[6], which is slightly below the five DNE21+ scenarios, consistent with the 2°C and 1.5°C emission reduction pathways. Between 2031 and 2050, the government Road map is within the range of the five DNE21+ scenarios, which is consistent.

As for hydrogen-based energy, hydrogen can be produced domestically by water electrolysis in Orderly 2.0C/1.5C and 1.5C-CO_2_CN, where further cost reduction of VRE is expected, while in other scenarios, it is exclusively imported from overseas. In 2030 and 2040, most of it is used in power generation, but by 2050, it is used in direct reduced iron (DRI) production in the iron and steel sector. As for ammonia, blue ammonia produced overseas is used in the power generation sector, partly because the cost reduction of VRE is relatively slow in Disorderly 2.0C/1.5C. It is also used in industrial sectors such as petrochemical sector as carbon-neutral fuel. e-methane is used in the residential and commercial sectors, other industrial sectors, and the power sector (with the introduction of CCS, it is practically a negative emission like BECCS). The e-methane is mainly produced overseas where renewable energy costs are low, and imported, however, under the 1.5C-CO_2_CN, domestic production using innovative methanation technology is also observed. Imported e-fuels other than e-methane are also used.

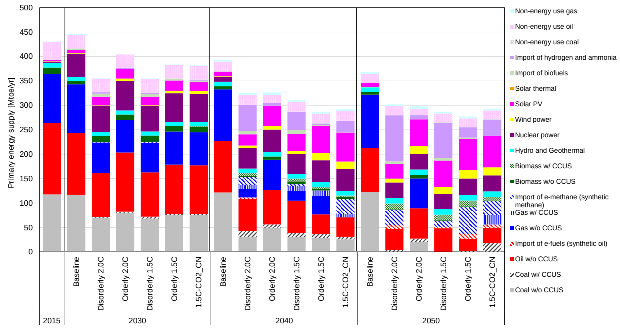


Figure 11 Primary energy supply (Japan)

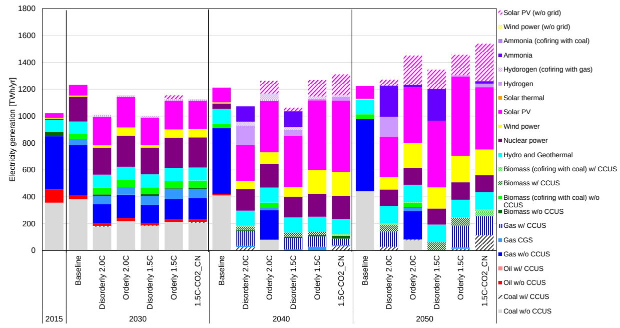


Figure 12 Electricity supply (Japan)

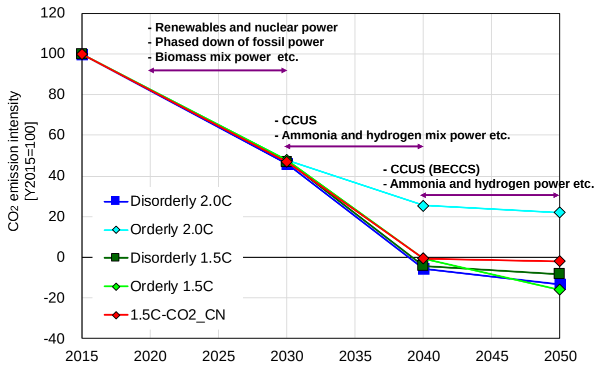


Figure 13 CO_2 intensity of electricity (Japan)

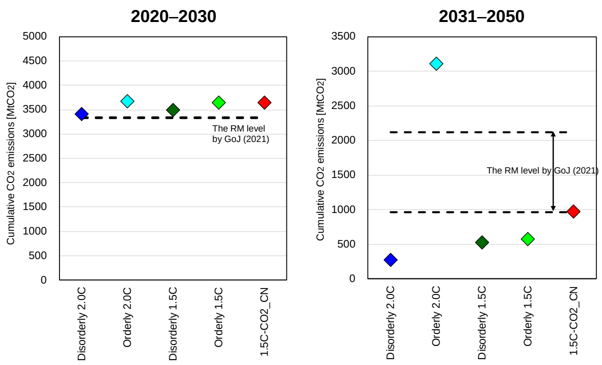


Figure 14 CO_2 emissions in power sector (Japan): comparison with the RM by GoJ

3.3. Gas and oil supply

Figure 15 shows the gas supply. Under Orderly 2.0C, the supply of natural gas supply keeps the current level or slightly decreases by 2050. Other scenarios predict greater uses of hydrogen or e-methane in 2040 and 2050. The choice between hydrogen and e-methane is sensitive depending on preconditions, such as the assumption of cost reduction timing. As in Figure 16, which shows CO_2 emissions in the gas sector, the CO_2 emission intensity is not improved in 2030 and 2040, compared to that in the power generation sector. Since natural gas has a low CO_2 intensity, its use is consistent with the 2°C and 1.5°C scenarios until around 2030 to 2040.

Figure 17 shows the oil (liquid fuels) supply. The oil use significantly decreases due to a decline in demand for transportation services, the improvements in vehicle fuel efficiency, and the shift to EVs, etc. in any scenario. This trend is notable particularly in Orderly 1.5C and 1.5C-CO_2_CN, which assumes high technological progress and cost reduction in renewable energy and EVs. The use of e-fuels can be also seen in 2050. Especially in Orderly 1.5C, in which the constraint on CO_2 storage expansion is assumed, oil is replaced with e-fuels more and more, as emission offset is limited and the price of e-fuels decreases due to further reductions in renewable energy costs.

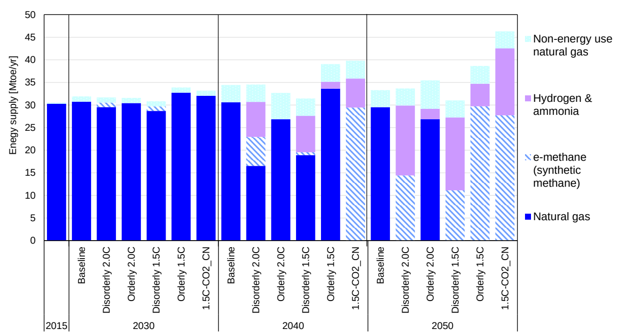


Figure 15 Gas supply (Japan)

Note) The uses in power, iron & steel, and petrochemical sectors are not included here and described in each sectoral analysis.

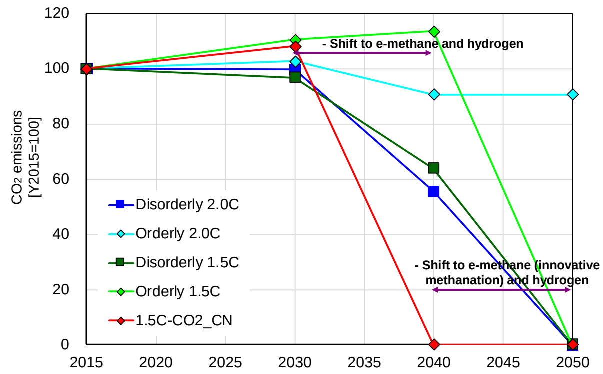


Figure 16 CO_2 emissions from gas (Japan)

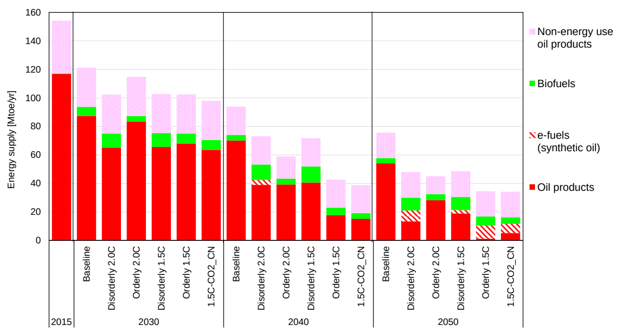


Figure 17 Oil (liquid fuels) supply (Japan)

Note) The uses in power sector are not included here.

3.4. Industry sector

Figure 18 shows the final energy consumption in industry. Coal use remains even in 2040 at a level close to that in 2030, for the usage in BF-BOF in the iron and steel sector. In 2050, there is no use of coal, and the uses of hydrogen, ammonia, and e-methane are observed in the scenarios other than Orderly 2.0C.

Figures 19 and 20 show the final energy consumption and crude steel production by technology in the iron and steel sector, respectively. As mentioned earlier, there is a considerable amount of coal used in 2040. There are also scenarios where BF-BOF steel manufacturing using external hydrogen, such as Super COURSE50, becomes economically efficient. In 2050, there is no use of coal, and the BF-BOF is completely replaced by hydrogen-using direct reduced iron (DRI) + electric furnace (EF) except for Orderly 2.0C, where total emission is predicted to be 70% lower than that in 2013.

The use of e-methane is used in the scrap EF process.

Figure 21 shows the CO_2 emissions intensity in the iron and steel sector. In any scenario, nearly zero emission is achieved in 2050 by introducing CCS in the BF after 2030, promoting the use of external hydrogen in some scenarios, and converting to the hydrogen-based DRI + EF from 2040 onwards. However, in Orderly 2.0C, where Japan does not make much progress in reducing CO_2 emissions, the BF-BOF without CCS continues to be used and some emissions remain even in 2050. Figure 22 shows a comparison of the DNE21+ scenarios and the roadmap formulated by the government of Japan for CO_2 emissions in the iron and steel sector. In the government's roadmap, while the upper limit for 2020-2030 has slightly higher emissions, other levels are within the range of the five DNE21+ scenarios and are consistent with the 2°C and 1.5°C emission reduction paths as a whole.

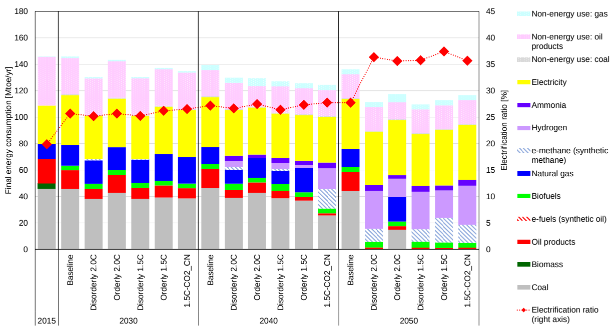


Figure 18 Final energy consumption in industry (Japan)

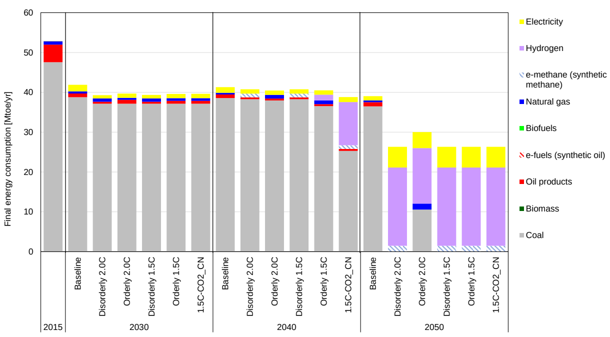


Figure 19 Final energy consumption in iron & steel (Japan)

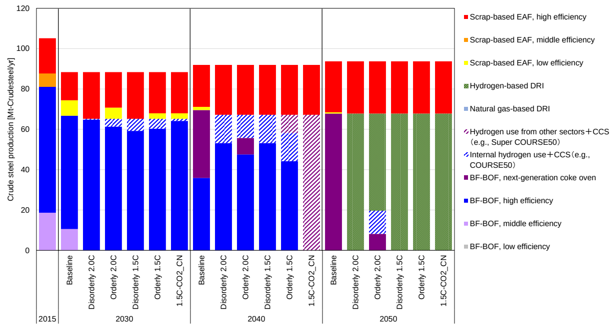


Figure 20 Steel production by technology (Japan)

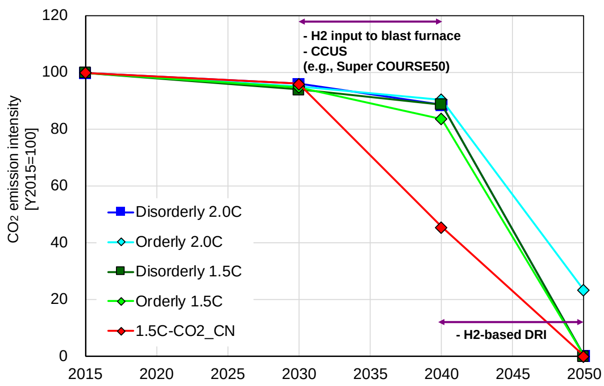


Figure 21 CO_2 intensity of iron & steel sector (Japan)

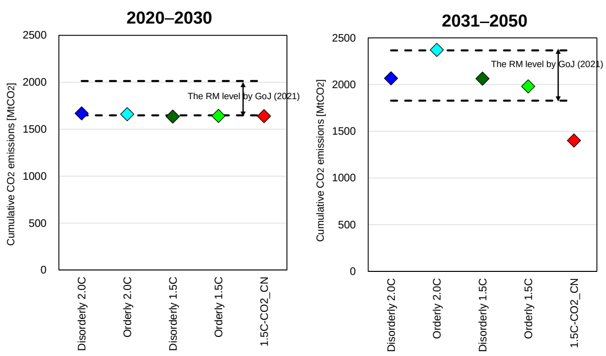


Figure 22 CO_2 emissions in iron & steel sector (Japan): comparison with the RM by GoJ

Figure 23 and Figure 24 show the final energy consumption and clinker production by technology in the cement sector, respectively. A shift from to gas is considered to be cost-effective in 2030 except Orderly 2.0C. A shift to gas is further promoted towards 2040, and e-methane is the main source by 2050. In 1.5C-CO_2_CN, which restricts the use of CDR, the deployment of CCS progresses, and therefore energy consumption is higher than in other scenarios. Figure 25 shows the CO_2 emissions intensity of the cement sector. In scenarios other than 1.5C-CO_2_CN, no CCS implementation is seen, and emission including process-derived CO_2 remains even in 2050. Net zero emission is achieved in 1.5C-CO_2_CN by introducing e-methane with CCS (net negative emissions).

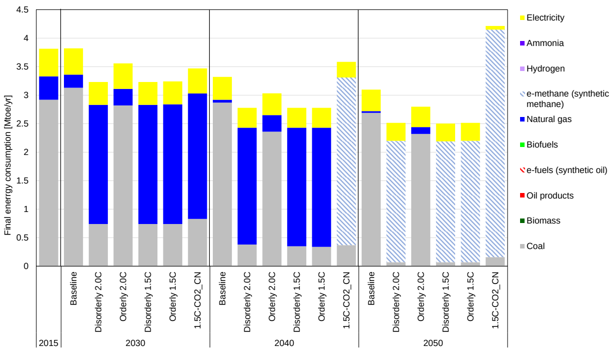


Figure 23 Final energy consumption in cement (Japan)

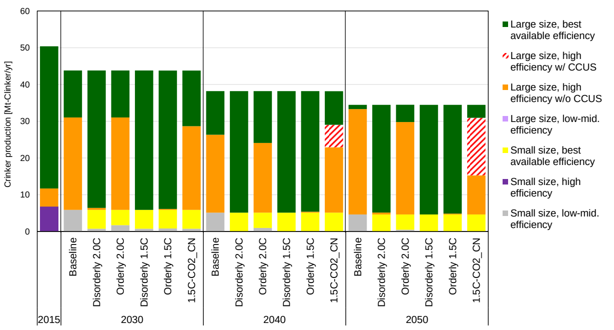


Figure 24 Clinker production by technology in cement sector (Japan)

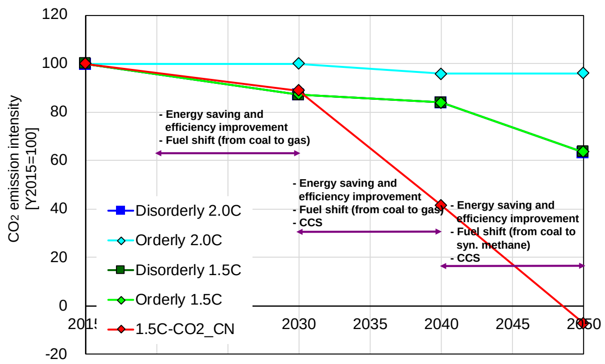


Figure 25 CO_2 intensity of cement sector (Japan)

The scenario analysis and roadmap development for the pulp and paper and the chemical sectors have been also conducted.

3.5. Transport sector

Figure 26 shows the final energy consumption in the transport sector. In the Orderly scenario and the 1.5C-CO_2_CN scenario, which assume significant reduction in the costs of renewable energy and EVs, electricity consumption particularly increases, and the use of e-fuels can be observed as well, from around 2040. In Orderly 1.5C and 1.5C-CO_2_CN, passenger cars are expected to be BEVs or FCEVs, and e-fuels is mainly used in trucks in the road transport sector.

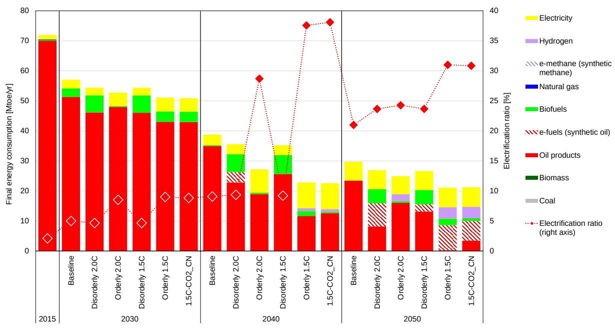


Figure 26 Final energy consumption in transport (Japan)

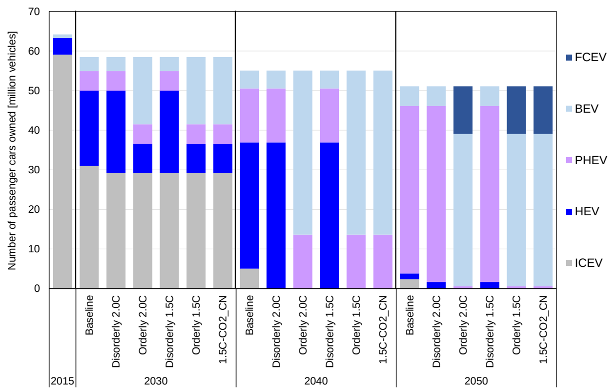


Figure 27 Number of passenger cars by technology (Japan)

Figure 27 shows the number of passenger cars by technology in Japan. In the Disorderly scenarios, which assume a medium level of EV technological progress, emission reduction measures for passenger cars focus on HEVs around 2030, expand to PHEVs afterward, and PHEVs become the main focus in 2050. On the other hand, in scenarios which assume high cost reduction in EVs, BEVs are expected to diffuse from an earlier stage and become dominant in 2040, and FCEVs are also expected to diffuse in 2050.

3.6. Residential and commercial sector

Figure 28 shows the final energy consumption in building. The improvement of electrification ratio is cost-effective as emissions reduction is stricter. In Orderly 2.0C, city gas is used as before, and in other scenarios, the gaseous fuels are e-methane or hydrogen.

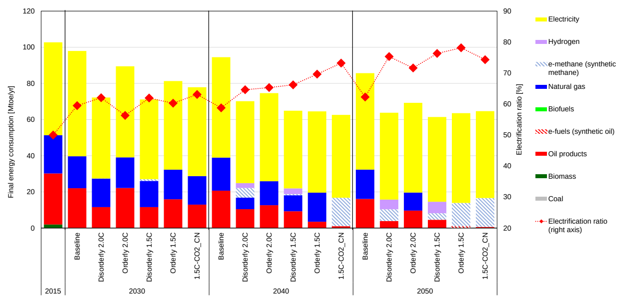


Figure 28 Final energy consumption in building (Japan)

4. Summary

Five scenarios that are consistent with the 2°C and 1.5°C targets and consistent with the NGFS and IEA scenarios were assumed and were analyzed including transition pathways, using the DNE21+ model, which enables quantitative and globally consistent analysis. Emission pathways varied significantly by sector and varied substantially by assumed scenarios of technology and other factors. In particular, there can be large differences depending on the projections of CDR. In addition, a comparison of emission pathways by sector shows that the power generation sector, which offers more emission reduction options, is required to improve its CO_2 emission intensity from a relatively early stage. This finding is consistent with IPCC and IEA scenarios. On the other hand, natural gas, which has a small CO_2 emission intensity, was assessed as a more economically efficient measure to be increased toward 2030 in Japan, even in the 2°C and 1.5°C scenarios. In addition, the steel sector was shown to have a scenario in which CO_2 reduction measures are difficult to implement and emissions will only be reduced by a maximum of 10% until around 2040. These analyses are generally consistent with the sectoral roadmaps developed by the Government of Japan for FY2021-22, and the government roadmap is consistent with not only the 2°C but also the 1.5°C emission reduction pathway.

In this analysis, we have presented only five scenarios. Even so, there is a large range, but in reality, there are uncertainties that cannot be fully taken into account in the five scenarios, and therefore, the interpretation of the scenarios needs to be carefully considered. Moreover, while the DNE21+ model is relatively detailed, the model still provides a highly simplified representation of real-world situations. The reality is that there are diverse agents and both re-tiring and new construction require a more complex transition process, including time-consuming coordination with the local community, however, the model is largely unable to account for these factors. To ensure transparency in the model analysis, non-transparent constraints are also intentionally not taken into account. Therefore, we believe that taking cost-effective measures from among the widest possible range of options, with a good understanding of these issues, will lead to the realization of CN at an earlier stage, and that this scenario analysis and roadmap will be useful in developing such a strategy.

It is an ongoing challenge to continue to follow technological trends and update the roadmap as appropriate, as well as to develop roadmaps for individual countries and regions other than Japan, to contribute to the promotion of its use in a wide range of countries.

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