Policy findings on Japan's transition to a decarbonized society derived from multi-model scenario analysis

March 29, 2021
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This report presents policy findings on Japan's long-term climate measures collated on the basis of scenario analyses using a number of scenarios from energy-economic and integrated assessment models. This is based on a special edition of Sustainability Science entitled "Energy Scenarios for Long-Term Climate Change Mitigation in Japan" in which the 35 Japan Modeling Intercomparison Project of the Stanford Energy Modeling Forum (EMF 35 JMIP) played a main role. For more information about the articles that appeared in this special edition, please refer to the editorial (Sugiyama, Fujimori, Wada, & Weyant, 2021) and to the articles themselves.

Introduction

In his inaugural policy speech on October 26, 2020, Prime Minister Yoshihide Suga declared an intention to reduce emissions of greenhouse gases (GHG) to net zero by 2050 (to achieve carbon neutrality). This pledge replaced Japan's previous Long-Term Strategy for reducing GHG emissions by 80% by 2050 with the more ambitious goal of net zero. The government announced its Green Growth Strategy in December 2020 and (as of the time of writing) is currently introducing amendments to the Act on Promotion of Global Warming Countermeasures. Revisions are also being made to Japan's Basic Energy Plan with the aim of having a new plan formulated by summer 2021. The 10th anniversary this month (March 2021) of the Great East Japan Earthquake and the accident at Tokyo Electric Power Company's Fukushima Dai'ichi Nuclear Power Plant comes at a pivotal time for debate on energy and climate policy.

Mr. Suga's speech emphasized "reforms and adjustments within industrial structures, the economy and society". This is certainly no understatement. While the issue of decarbonization has gained widespread recognition, it is a transition that will require the mobilization of a wide range of measures to accelerate both technological innovation and changes within society. Achieving this unprecedented transformation in energy policy will require improvements in scientific evidence from a diverse range of fields.

Model-based energy scenarios are one such form of scientific evidence. The use of scenarios in climate and energy policy has expanded considerably in recent times, prompted by the shift from the top-down approach of the Kyoto Protocol to the hybrid top-down/bottom-up regime of the Paris Agreement.

While the uncertainties from energy scenarios widely acknowledged, the uncertainties that arise out of differences in the models used are of particular importance (Krey, 2014). In the case of complex models with a high degree of nonlinearity, it is not uncommon for different models to produce different results even when working with the same assumptions. Accordingly, the uncertainties that come from differences between models need to be explicitly considered and analyzed when making policy judgements. The Energy Modeling Forum (EMF) at Stanford University has been undertaking research on this basis since the 1970s (Huntington et al., 1982).

The EMF 35 Japan Model Intercomparison (JMIP) (Energy Modeling Forum, n.d.) project undertook a multi-model scenario analysis of Japan's 2030 reduction targets and Long-Term Strategy (2050 reduction targets) that considered a variety of different uncertainties. Japan's current Nationally Determined Contribution (NDC) is a 26% reduction relative to FY2013 by FY2030 and the Long-Term Strategy is to target an 80% reduction by 2050 (the NDC is to be updated during this current year (as of this writing)). While a 100% emissions reduction was included in the EMF 35 JMIP scenario design, given that the project commenced in April 2017, the main scenarios used in the analysis were based on an 80% reduction by 2050. Nevertheless, the results of the EMF 35 JMIP analysis serve as a basis for a net-zero mitigation analysis.

Models used and scenario design

The uncertainties considered in EMF 35 JMIP were energy policy stringency (emission constraints), technological constraints, service demand levels, and energy import costs (Sugiyama, Fujimori, Wada, Oshiro, et al., 2021).

Table 1 lists the models used. While these included models that considered a number of different GHGs, the study focused on CO_2 emissions resulting from energy use and industrial processes. While not all models for Japan were included, most of the main ones were.

Table 1. List of models used

Model	Scope	Institution	Model type
AIM/Enduse-Japan V2.1	Japan	Kyoto University, National Institute for Environmental Studies	Recursive dynamic, partial equilibrium
AIM/Hub-Japan 2.1	Japan	Kyoto University, National Institute for Environmental Studies, Institute for Global Environmental Strategies	Recursive dynamic, general equilibrium
DNE21 Version 1.3	Global	Graduate School of Engineering, The University of Tokyo	Intertemporal optimization, partial equilibrium
IEEJ Japan ver. 2017	Japan	The Institute of Energy Economics, Japan	Intertemporal optimization, partial equilibrium
TIMES-Japan 3.1	Japan	The Institute of Applied Energy	Intertemporal optimization, partial equilibrium

Table 2 lists the scenario designs.

Table 2. List of scenarios. For simplicity, only policy scenarios are shown (excluding the baseline). Baseline scenarios are indicated by Baseline_Def, etc.

Dimension	Scenario	Explanation
Emission constraints	26by30+80by50_Def	NDC & Long-Term Strategy
	26by30+70by50_Def	NDC & 70% reduction by 2050
	26by30+90by50_Def	NDC & 90% reduction by 2050
	26by30+100by50_Def	NDC & 100% reduction by 2050
	16by30+80by50_Def	16% reduction by 2030, followed by Long-Term Strategy
	36by30+80by50_Def	36% reduction by 2030, followed by Long-Term Strategy
Sensitivity analysis of technology	26by30+80by50_NoCCS	Carbon capture & storage (CCS) is not available
	26by30+80by50_LimNuc	Limited use of nuclear power
	26by30+80by50_NoNuc	Use of nuclear power is not available
	26by30+80by50_HighInt	Significant issues with integrating variable renewable energy into grid
	26by30+80by50_LoInt	Minimal issues with integrating variable renewable energy into grid
	26by30+80by50_LoVREcost	Halving of cost of variable renewable energy
	26by30+80by50_HiVREcost	Doubling of cost of variable renewable energy
	26by30+80by50_LoVREpot	Halving of variable renewable energy availability
	26by30+80by50_HiVREpot	Doubling of variable renewable energy availability
	26by30+80by50_LoStorageCost	Significant reduction in cost of energy storage
Service demand levels	26by30+80by50_LoDem	Low-GDP-growth scenario
	26by30+80by50_LoDemBld	Low-GDP-growth + halving of service demand from consumer sector
	26by30+80by50_LoDemTra	Low-GDP-growth + halving of service demand from transportation sector
	26by30+80by50_LoDemInd	Low-GDP-growth + halving of service demand from industrial sector
Energy import costs	26by30+80by50_HiImportCost	Doubling in price of energy imports

The naming convention for scenarios was: <policy dimension>_<other parameter settings>, where <policy dimension> was either "Baseline" or used the format "<xx>%by30+<yy>%by50" to indicate a reduction of xx% by 2030 and yy% by 2050.

The following two main scenarios were used.

Baseline_Def: Default parameter settings with no climate policy

26by30+80by50_Def: Default parameter settings with Nationally Determined Contribution (NDC) (26% reduction relative to FY2013 by FY2030) and Long-Term Strategy (80% reduction by 2050)

Considering different levels of emission reduction provides a means of assessing how factors such as cost change in response to changes in policy targets (e.g., 26% reduction by FY2030, 80% by 2050).

As with past studies by EMF, the analysis of technological factors is done by assessing the consequences of idealized scenarios under which specific technological options are unavailable. Also included are sensitivity analyses of technologies such as variable renewable energy, electricity system integration, and energy storage costs. In recognition of its being a major political issue, three scenarios were considered for nuclear power, namely the default assumption in each model, a scenario of limited use of nuclear power, and a scenario where nuclear power is unavailable. Caution is needed as the availability of technologies depends on their development, their public acceptance, and by a mix of both factors.

Energy service demand heavily influences primary energy demand, and is also strongly related to the difficulty of mitigation measures. The study used scenarios that assumed a low rate of economic growth and also sensitivity analyses based on idealized scenarios of a halving in service demand from the industrial, transportation, and consumer sectors, respectively. While these are idealized scenarios, numerous factors can cause changes in service demand, including improvements in material efficiency or sudden demand shocks like that during the COVID-19 pandemic of 2019-2021.

Sensitivity analyses were also performed for energy import costs. Japan is heavily dependent on energy imports, currently producing less than 10% of its own energy. This import dependence may well continue even after a shift to a clean energy system. In fact, the Japanese government is currently studying the potential for importing large quantities of hydrogen, ammonia and other fuels from suppliers such as Australia. This makes it worth conducting sensitivity analyses on changes in energy import costs.

The same values for gross domestic product (GDP) and population were used across all scenarios. Population data was obtained from the National Institute of Population and Social Security Research and sources such as the Middle of the Road case (SSP2) in Shared Socioeconomic Pathways (SSP) were used for GDP. SSP data is widely used in long-term energy scenario analysis and internationally by organizations such as the Intergovernmental Panel on Climate Change (IPCC).

<u>Need for strengthening (broadening and deepening) of long-term mitigation measures to achieve Long-Term Strategy</u>

The results of the multi-model analysis indicate that the Long-Term Strategy targets that the Japanese government submitted to the United Nations Framework Convention on Climate Change in 2019 will require large emission reductions across all sectors to achieve the 80% reduction in GHG emissions by 2050. Current measures are inadequate and need to be considerably strengthened.

Figure 1 shows how CO_2 emissions trend over time in the electricity, transportation, consumer (home and work), and industrial (energy and industrial processes) sectors. For Japan as a whole to achieve an 80% reduction in emissions by 2050 will require an unprecedented scale of reductions across all sectors. Except for the general equilibrium model, the sector with the highest level of residual emissions is the industrial sector (Ju et al., 2021).

Assuming mitigation measures are adopted in the form of carbon taxes or emissions trading, the carbon price will increase with time. A median value of zero was found for the carbon price in the models up to 2020, with this rising to around 80,000 yen in 2050 under standard assumptions (converted at a rate of 100 JPY to 1 USD for simplicity). That all sectors will contribute to emission reductions, as indicated in Figure 1, because this high carbon price applies to all of them. While comparing models with reality is difficult, according to a report on effective carbon prices published in 2018 by the Organisation for Economic Co-operation and Development (OECD), there is a shortfall of 69% in the proportion of emissions covered by carbon pricing, assuming an effective price in Japan of around the 3000 yen/t-CO_2 level (specifically, 30 EUR converted at a rounded rate of 100 JPY/EUR).

A wide range of different mitigation measures can be considered in practice, including direct regulation, pricing mechanisms, innovation policies, and digital policies. Accordingly, although all of these are represented in the models in the idealized form of a carbon price, this should not be interpreted as meaning that an explicit carbon tax should be adopted at the high carbon price used in the models. That is, various different policies have the effect of raising the implicit carbon price. While there is no great problem with the current level for the base measures, there is a need over the long-term for mitigation measures to be strengthened, and also broadened and deepened, if net-zero and the Japanese government's previously stated target of an 80% reduction by 2050 are to be achieved.

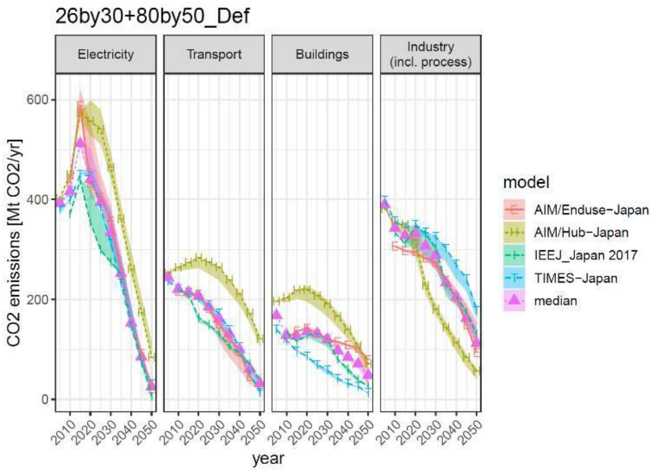

Figure 1. CO_2 emissions by different sectors. The shaded regions indicate the spread across different scenarios (no nuclear power, no CCS, and low GDP)

Robust policy packages for mitigation measures

Along with highlighting the uncertainties, the multi-model study can also indicate which areas offer the most robust policy options. Improving economy-wide energy efficiency, encouraging demand-side electrification (Sakamoto et al., 2021), and a shift to low-carbon and decarbonized electricity generation (Shiraki et al., 2021) were all very robust measures (measures shown to be effective regardless of the scenario assumptions or choice of model). Factors such as what exact form electricity generation should take, on the other hand, remain uncertain and, while decarbonizing electricity generation itself is a robust policy goal, it is essential to retain flexibility in the energy mix and to adopt an adaptable approach under which policies are revised in the light of new information such as technological progress.

Figure 2 shows various key indicators that relate to mitigation measures. The graphs show four different cases, including no nuclear power, no carbon capture and storage (CCS), and low GDP growth as well as the standard input assumptions for each model. While the models differ in a variety of ways, improving energy efficiency across the economy as a whole, significantly reducing CO_2 emissions per unit of electricity generated, and demand-side electrification (increasing the proportion of end-user energy consumed in the form of electricity) were all robust conclusions in the sense that they were shown to be effective measures regardless of models. Also evident was a large increase in the proportion of electricity generated from renewable sources (except under more extreme assumptions such as no restrictions on use of nuclear power or the availability of large amounts of low-cost biomass) (Shiraki et al., 2021). The proportion of primary energy derived from fossil fuels also followed a declining trend.

There were other areas, however, where considerable uncertainties remained. Figure 3 shows that there were major differences in the makeup of electricity generation both between different models and between different scenario settings for the same model. In terms of differences between models, some indicate the importance of thermal power plants with CCS, some show a major increase in renewable energy, while others have hydrogen power generation playing an important role. While the electricity generation mix is a matter of considerable public interest, the model analyses showed no clear-cut answers, including with regard to nuclear power.

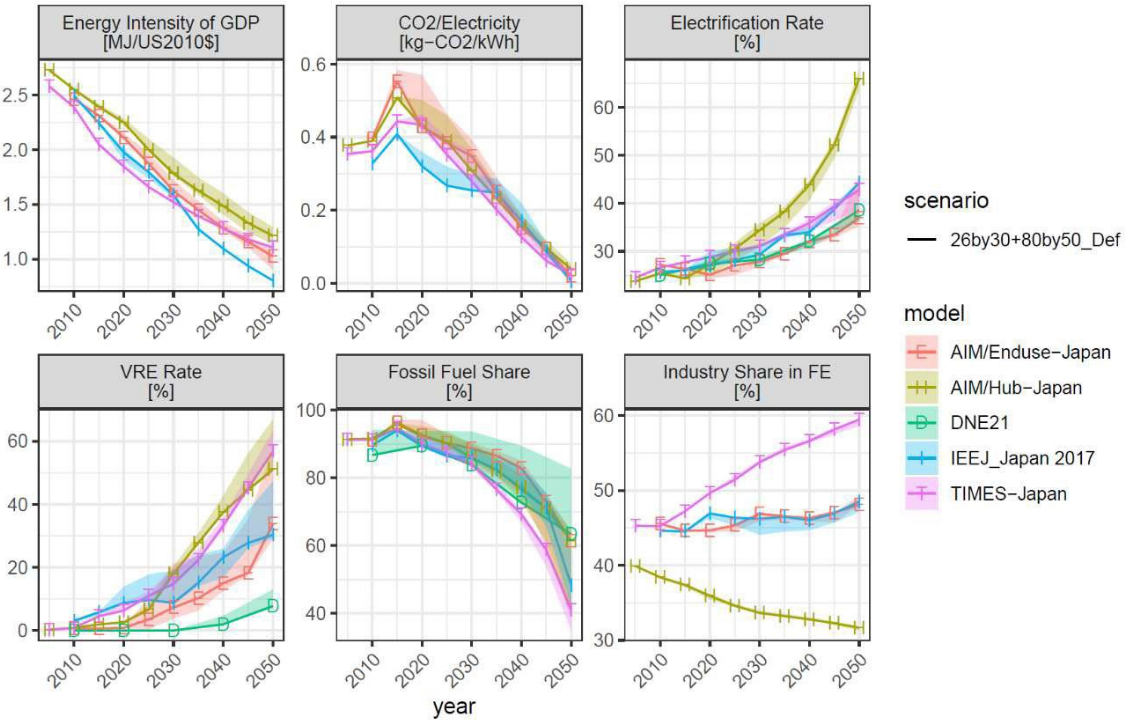

Figure 2. Analysis of key indicators relating to long-term mitigation measures.
Top left: Energy use per unit of GDP, Top middle: CO_2 emissions per unit of power generation, Top right: Electricity as a percentage of total end-user energy consumption, Bottom left: Solar and wind (variable renewable energy) share of secondary electric power, Bottom middle: Fossil fuel share of primary energy, Bottom right: Industry's share of end-user energy consumption. The shaded regions indicate the spread across different scenarios
(no nuclear power, no CCS, and low GDP).

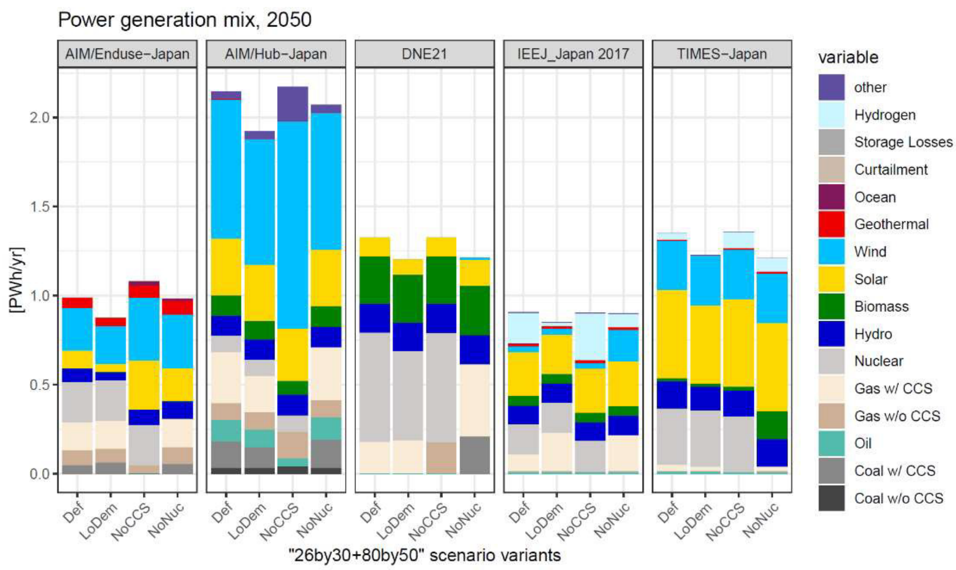

Figure 3. 2050 electricity generation mix under four 26by30+80by50 scenarios. Def: Default settings, LoDem: Low GDP growth (= low end-user energy demand), NoCCS: No CCS, and NoNuc: No nuclear power

Need for both ongoing incremental innovation and revolutionary innovation

The cost of mitigation measures is an important consideration for the viability of long-term climate measures and the cost to the public. If the cost is low, the impact on the economy is reduced and policies become more politically viable. Major progress on innovation also has a positive impact on the economy. Moreover, the lower the cost of mitigation measures, the deeper the cuts that can be made in emissions for the same cost to the overall economy.

The multi-model analysis indicates that Japan's GDP in 2050 will be about 3% lower otherwise would be if long-term climate measures are adopted, and that this will incur additional energy system costs of about 0.8 to 0.9% of GDP. There are numerous ways in which costs can be reduced, one of which is the "discontinuous innovation" emphasized in the Long-Term Strategy. Likewise, if significant reductions in cost can also be achieved using existing technologies rather than new technological innovations, that too will be a considerable help in keeping mitigation costs down. Put another way, ongoing incremental innovation is also important.

The Long-Term Strategy aims to turn renewable energy into a major source of electricity generation that is both economically self-sustaining and decarbonized. Unfortunately, the cost of renewable energy is consistently higher in Japan than elsewhere in the world. While there are areas in the world where renewable energy is the lowest-cost technology for electricity generation, solar PV for example is roughly twice as expensive in Japan as Germany and this is raising the cost of measures such as feed-in tariff systems and energy auctions, increasing the cost of levies on electricity prices. The model analysis indicates that the idealized case of halving the cost of renewable energy reduces the median value for the cost of measures across the different models by about 10%. As the divergence from international prices can also be seen as indicating scope for cutting costs, policies for doing so are also important.

The multi-model calculations also show the importance of large-scale carbon dioxide removal (CDR) technologies for achieving net-zero emissions. As Japan has only just begun getting involved in the development of CDR technology through initiatives such as the Moonshot R&D Program, this is an area where innovation and development of technologies like electricity generation from biomass with CCS or the direct air capture of CO_2 need to be strengthened significantly with the aim of scaling up.

Future research challenges

While EMF 35 JMIP has provided worthwhile findings, many unresolved issues remain. Foremost of these is that an analysis is needed that extends out beyond 2050 and in which the GHG reduction target is increased from 80% to 100% or more. While a number of papers (Oshiro et al., 2018 and Schreyer et al., 2020) and other reports have already analyzed the net-zero target, further research is called for as no multi-model comparisons of models analyzing the net-zero target have yet appeared. This also needs to include an analysis of the role of CDR (Kato & Kurosawa, 2021).

The second issue is the need for an analysis of specific measures that goes beyond an analysis of carbon pricing. With regard to innovation, for example, there is a need to improve scenario design so as to explicitly incorporate government targets for technology development like those in the Green Growth Strategy. In the case of renewable energy, analyses of system integration (Matsuo & Komiyama, 2021) and the role of offshore wind power (Komiyama & Fujii, 2021) will likely be important. In terms of economic impacts, along with carbon pricing design (Takeda & Arimura, 2021), more detailed analyses covering targets for 2030 and 2040 (Silva Herran & Fujimori, 2021) are also needed as well as for demand-side management and their economic impacts (Oshiro & Fujimori, 2021).

Finally, beyond the cross comparison of different models, there are also numerous potentially important research topics that relate to energy scenarios. Examples such as participatory scenario modeling (Voinov et al., 2016), scenario communication and the use of scenarios in education (Suzuki et al., 2021), and the integration of scenarios with the study of socio-technical transitions (Frank W. Geels et al., 2016; F.W. Geels et al., 2020) are much needed given increase in the societal importance of scenarios. This makes it vital for Japan that these studies proceed.

Conclusions

The following summarizes the multi-model analysis and its implications.

- Large reductions of GHG will be needed in all emitting sectors if substantial reductions in GHG emissions (80%, net zero) are to be achieved by 2050. While electricity generation is a frequent focus of debate, it should be kept in mind that measures are needed across all sectors.
- A distinction should be made between "robust" and uncertain measures. In the model analysis, improving economy-wide energy efficiency, promoting demand-side electrification, and a shift to low-carbon and decarbonized electricity generation were all robust conclusions in the sense that they were shown to be effective measures regardless of the scenario assumptions and choice of model. The exact make-up of the energy mix, on the other hand, remains uncertain. While policy debate tends to focus on particular energy mixes, when looking ahead as far as 2050, it is essential to retain flexibility in the energy mix and to adopt a flexible policy framework that can be revised as needed.
- Large-scale CDR (the removal of CO_2 from the atmosphere) will be important for achieving net-zero emissions. This means there is a need to target large-scale deployment, accelerating deployment on the basis of a major step up in innovation and development for technologies such as biomass power with CCS and the direct air capture of CO_2.
- While new innovations such as CDR are vital, the need for ongoing incremental innovation should also not be overlooked. Solar power, for example, is roughly twice as expensive in Japan as Germany and this is raising the cost of measures such as feed-in tariff systems and energy auctions, imposing a greater burden on electricity prices. As bringing the cost of solar PV into line with international level would permanently reduce the political cost, policies to reduce the cost of renewable energy should be further stepped up.

<u>Reference</u> (those published in 2021, *Sustainability Science*, are in the special issue.)

Energy Modeling Forum, J. (n.d.). *EMF 35: Japan model intercomparison project (JMIP) on long-term climate policy.* Retrieved February 13, 2021, from https://emf.stanford.edu/projects/emf-35-japan-model-intercomparison-projectjmip-long-term-climate-policy

Geels, Frank W., Berkhout, F., & van Vuuren, D. P. (2016). Bridging analytical approaches for low-carbon transitions. *Nature Climate Change*, *6*(6), 576–583. https://doi.org/10.1038/nclimate2980

Geels, F.W., McMeekin, A., & Pfluger, B. (2020). Socio-technical scenarios as a methodological tool to explore social and political feasibility in low-carbon transitions: Bridging computer models and the multi-level perspective in UK electricity generation (2010–2050). *Technological Forecasting and Social Change,* 151, 119258. https://doi.org/10.1016/j.techfore.2018.04.001

Huntington, H. G., Weyant, J. P., & Sweeney, J. L. (1982). Modeling for insights, not numbers: The experiences of the energy modeling forum. *Omega, 10*(5), 449–462. https://doi.org/10.1016/0305-0483(82)90002-0

Ju, Y., Sugiyama, M., Silva Herran, D., Oshiro, K., Kato, E., & Matsuo, Y. (2021). Industrial Decarbonization Under Japan's National Mitigation Scenarios: A Multi-Model Analysis. *Sustainability Science.* https://doi.org/10.1007/s11625-021-00905-2

Kato, E., & Kurosawa, A. (2021). Role of negative emissions technologies (NETs) and innovative technologies in transition of Japan's energy systems toward net-zero CO2 emissions. *Sustainability Science*. https://doi.org/10.1007/s11625-021-00908-z

Komiyama, R., & Fujii, Y. (2021). Large-scale integration of offshore wind into the Japanese power grid. *Sustainability Science.* https://doi.org/10.1007/s11625-021-00907-0

Krey, V. (2014). Global energy-climate scenarios and models: A review. *WIREs Energy and Environment, 3*(4), 363–383. https://doi.org/10.1002/wene.98

Matsuo, Y., & Komiyama, R. (2021). System LCOE of variable renewable energies: A case study of Japan's decarbonized power sector in 2050. *Sustainability Science.* https://doi.org/10.1007/s11625-021-00914-1

Oshiro, K., & Fujimori, S. (2021). Stranded investment associated with rapid energy system changes under the mid-century strategy in Japan. *Sustainability Science*. https://doi.org/10.1007/s11625-020-00862-2

Oshiro, K., Masui, T., & Kainuma, M. (2018). Transformation of Japan's energy system to attain net-zero emission by 2050. *Carbon Management, 9*(5), 493–501. https://doi.org/10.1080/17583004.2017.1396842

Sakamoto, S., Nagai, Y., Sugiyama, M., Fujimori, S., Kato, E., Komiyama, R., Matsuo, Y., Oshiro, K., & Silva Herran, D. (2021). End-use decarbonization and electrification: EMF 35 JMIP study. *Sustainability*

Science.

Schreyer, F., Luderer, G., Rodrigues, R., Pietzcker, R. C., Baumstark, L., Sugiyama, M., Brecha, R. J., & Ueckerdt, F. (2020). Common but differentiated leadership: Strategies and challenges for carbon neutrality by 2050 across industrialized economies. *Environmental Research Letters, 15*(11), 114016. https://doi.org/10.1088/1748-9326/abb852

Shiraki, H., Sugiyama, M., Matsuo, Y., Komiyama, R., Fujimori, S., Kato, E., Oshiro, K., & Silva Herran, D. (2021). The role of renewables in the Japanese power sector: Implications from the EMF35. *Sustainability Science*. https://doi.org/10.1007/s11625-021-00917-y

Silva Herran, D., & Fujimori, S. (2021). Beyond Japanese NDC: energy and macroeconomic transitions towards 2050 in emission pathways with multiple ambition levels. *Sustainability Science.* https://doi.org/10.1007/s11625-021-00930-1

Sugiyama, M., Fujimori, S., Wada, K., Oshiro, K., Kato, E., Komiyama, R., Silva Herran, D., Matsuo, Y., Shiraki, H., & Ju, Y. (2021). *EMF 35 JMIP study for Japan's longterm climate and energy policy: Scenario designs and key findings.* https://doi.org/10.1007/s11625-021-00913-2

Sugiyama, M., Fujimori, S., Wada, K., & Weyant, J. (2021). Introduction to the Special Feature on Energy Scenarios for Long-Term Climate Change Mitigation in Japan. *Sustainability Science*. https://doi.org/10.1007/s11625-021-00931-0

Suzuki, K., Shibuya, T., & Kanagawa, T. (2021). Effectiveness of a game-based class for interdisciplinary energy systems education in engineering courses. *Sustainability Science*. https://doi.org/10.1007/s11625-021-00912-3

Takeda, S., & Arimura, T. H. (2021). A Computable General Equilibrium Analysis of Environmental Tax Reform in Japan. *Sustainability Science, this issue.* https://doi.org/10.1007/s11625-021-00903-4

Voinov, A., Kolagani, N., McCall, M. K., Glynn, P. D., Kragt, M. E., Ostermann, F. O., Pierce, S. A., & Ramu, P. (2016). Modelling with stakeholders – Next generation. *Environmental Modelling & Software, 77*, 196–220. https://doi.org/10.1016/j.envsoft.2015.11.016