Systems Analysis Group

Members (As of Dec. 2021)

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
Hironobu Yamakawa, Senior Researcher
Ayami Hayashi, Senior Researcher
Atsuko Fushimi, Senior Researcher
Tsutomu Soejima, Senior Researcher
Noritaka Mochizuki, Senior Researcher (concurrent)
Joni Jupesta, Senior Researcher
Yuko Nakano, Researcher
Naoko Onishi, Researcher
Hitotsugu Masuda, Researcher
Teruhisa Ando, Researcher
Yuko Matsuoka, Researcher
Kiyomi Yamamoto, Assistant Researcher
Misako Saito, Assistant Researcher
Kiyomi Kitamura, Assistant Researcher
Sachiko Kudo, 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. This article presents the analyses on 1) the response measures for achieving carbon neutrality (Section 1), and 2) the emission reduction efforts including emission reduction costs for the 2030 emission reduction targets, and the impacts on whole economy (Sections 2 and 3).

1. Analysis on scenarios achieving carbon neutrality by 2050

Then Prime minister Suga stated that Japan seeks carbon neutrality (CN) by 2050 in October, 2022. The CN by 2050 will be consistent with the emission pathways for the below 1.5 °C of temperature goal. The new Strategic Energy Plan, the Climate Change Adaptation Plan, and the Long-term Strategy under the Paris Agreement were decided by the Cabinet of Japan in October 2021.

According to the request by the Strategic Policy Committee of Advisory Committee in Natural Resources and Energy, which had discussed the Strategic Energy Plan, RITE provided the analyses results for several scenarios for CN by 2050, using a global energy and climate change mitigation model, DNE21+ (Reference 1) and others) in May, 2021[2)]. This section introduces the overview of the scenario analyses.

1.1. Overview of caron neutrality

The overview of primary energy supply systems to achieve net-zero emissions is shown in Figure 1. Achieving CN requires decarbonized energy supply basically, however, energy saving is also important, if the least cost measures, and technological, social and economic constraints on each energy source are taken into account. Social innovations including sharing and circular economy associated with digital transformation (DX) will be a key for the CN as well as energy savings of each technology.

On top of that, renewable energy, nuclear power, and fossil fuels with CO_2 capture and storage (CCS) are required as primary energy sources, in principle. In Japan, because all of these energy sources have cost and potential constraints etc., hydrogen import from overseas will be also an important option as a cost-efficient measure. Hydrogen can be produced typically by renewables (green hydrogen) and fossil fuels with CCS (blue hydrogen). To increase more convenient uses of hydrogen, ammonia and synthetic fuels (synthetic methane and liquid fuels) synthesizing with nitrogen and carbon will play important roles.

Considering several large uncertainties in the outlooks of technologies, social constraints, and so on, several scenarios should be assumed and analyzed having consistency with total systems and costs, which enables a mathematical model to analyze whole energy systems quantitatively and comprehensively.

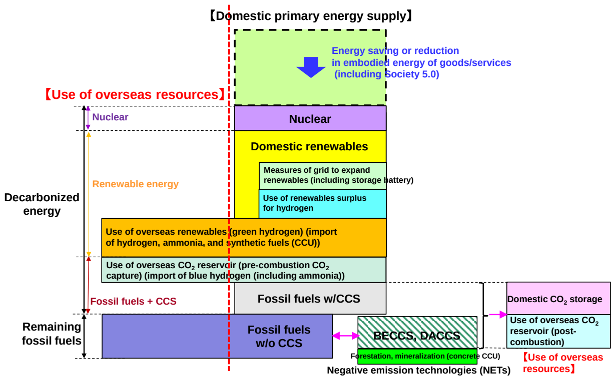

Figure 1 Overview of achieving net-zero emissions

1.2. Overview of model

Using a global energy systems model DNE21+ (Dynamic New Earth 21 plus), the emission reduction measures for carbon neutrality by 2050 are analyzed. DNE21+ is a global model with consistencies across 54 countries and regions, and intertemporal years up to 2100. In the model, global warming response measures for approximately 500 specific technologies can be evaluated in detail; energy supply technologies, such as electricity and hydrogen-based energies, CO_2 capture, utilization and storage (CCUS), and energy demand-side technologies in iron and steel, cement, paper and pulp, chemical, aluminum, transport, and some appliances of building sector are modeled with bottom-up treatments.

For analyzing large deployments of variable renewable energy (VRE) in Japan, the grid integration costs of VRE are estimated using a power systems model having 5 disaggregated Japan's regions and one hour time step, which was developed by the University of Tokyo and Institute of Energy and Economics, Japan (IEEJ). The grid integration cost curves of VRE are integrated into DNE21+.

1.3. Assumed scenarios

Tables 1 and 2 show the assumed scenarios for the CN in 2050. Here, as well as the CN of GHGs in 2050 in Japan, the globally least cost measures for the 1.5 °C goal are also assumed ("Offset emission credits of overseas" case). In addition, "Synthetic fuel utilization" case is analyzed.

Table 1 Scenarios assumed for model analyses

		GHG emission reduction in 2050	Technology assumption (cost / performance)
Offset emission credits of overseas (The least-cost measures in the world = Equal marginal abatement costs among nations)		Domestic emission reductions are endogenously determined.	**Standard case** (Note: It is premised that RE is diffused due to suspected inertial force in high share RE scenario.)
Reference case		**▲100%** (For other than Japan, ▲100% for each western country, and ▲100% for the others as a whole)	
Assuming high share of RE under Standard case	**1. Renewable Energy 100%**		
Assuming each technology is further accelerated or expanded.	**2. Renewable Energy Innovation**		**Acceleration of RE cost reduction**
	3. Nuclear Power Utilization		**Expansion of nuclear power deployment**
	4. Hydrogen Innovation		**Acceleration of hydrogen cost reduction**
	5. CCS Utilization		**Expansion of CO_2 storage potential**
	6. Synthetic fuel Utilization		**Acceleration of RE cost red. + Constraints of CO2 intern'l transportation**
	7. Demand Transformation		**Expansion of car-/ride-sharing**

Table 2 Scenarios regarding technology assumptions

Scenario		Cost of renewable energy	Ratio of nuclear power	Cost of hydrogen	CCUS (Storage potential)	Fully autonomous driving (car- & ride-sharing)
Offset emission credits of overseas (The least-cost measures in the world = Equal marginal abatement costs among nations)		Standard cost	Max. 10%	Standard cost	Domestic storage: max. 91 $MtCO_2$/yr; Overseas transportation: max. 235 $MtCO_2$/yr	Standard assumption: no fully autonomous cars
Reference Case						
Assuming high share of RE under standard case	**1. Renewable Energy 100%**		0%			
Assuming each technology is further accelerated or expanded.	**2. Renewable Energy Innovation**	Low cost	Max. 10%			
	3. Nuclear Power Utilization[*2]	Standard cost	Max. 20%			
	4. Hydrogen Innovation		Max. 10%	Hydrogen production such as water electrolysis, hydrogen liquefaction facility cost: halved		
	5. CCS Utilization			Standard cost	Domestic: max. 273 $MtCO_2$/yr; Overseas: max. 282 $MtCO_2$/yr	
	6. Synthetic Fuel Utilization	Low cost			Domestic: max. 91Mt, Overseas: 0Mt	
	7. Demand Transformation	Standard cost			Domestic: max. 91 $MtCO_2$/yr; Overseas: max. 235 $MtCO_2$/yr	Realization and diffusion of fully autonomous driving and expansion of car- & ride-sharing after 2030, and decrease in material production due to reduction of the number of automobiles

1.4. Results

The GHG emissions in Japan are shown in Figure 2. Under the globally least cost measure for the 1.5 °C scenario, the 2050 emissions in Japan are estimated to be -63% compared to 2013. This is because there are larger potentials with smaller costs of CO_2 removal technologies (CDR) (or negative emission technologies: NETs) in the world than in Japan. Particularly the regions and countries where large potentials of bioenergy, VREs, and CO_2 geological storage exist could serve the opportunities of CDR such as bioenergy with CCS (BECCS) and direct air CO_2 capture and storage (DACCS) cost-efficiently.

While recognizing the emissions reduction opportunities in overseas, the domestic emission reduction measures should be considered. Even for achieving the CN within Japan, DACCS will be an important measure. However, if CO_2 storage potentials including the opportunities of transport of CO_2 to overseas are limited, the contributions of DACCS are reduced and the roles of synthetic fuels (synthetic methane and synthetic liquid fuels) will increase. Meanwhile, there are no feasible solutions for the 2050 CN in Japan for any assumed scenarios under the socioeconomic and other assumptions without DACCS.

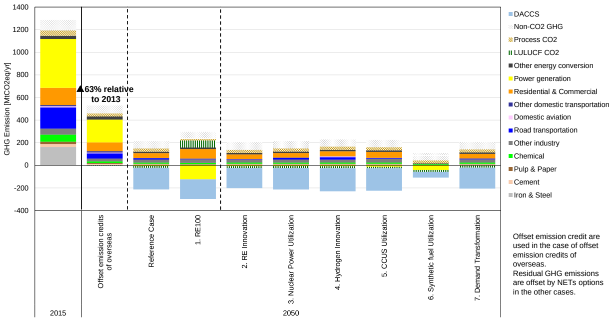

Figure 2 GHG emissions in Japan for CN by 2050

Figures 3, 4 and 5 show primary energy supply, electricity generation, and final energy consumption in Japan, respectively.

As seen in Figure 3, energy savings are important for all of the scenarios, and approximately 25% of primary energy savings can be observed. Renewable energy, CCS, and nuclear power will play important roles for the CN. The maximum constraints are assumed for the deployments of CCS and nuclear power, and the maximum deployments of both two will be the cost-efficient measures for the CN in Japan (only except for CCS transport to overseas in the CCUS utilization case). Although the cost reductions of VREs are assumed, the costs also increase as larger deployments of VRE, and wide ranges of costs are estimated for VREs accordingly. Thus, according to the estimations under the least cost of whole energy systems, combinations of deployments of several emissions reduction measures including DACCS and imports of hydrogen, ammonia and synthetic fuels can be estimated.

As contrasted with primary energy, electricity generations increase compared to the current levels in almost all the scenarios. Electrification is an important option for the CN. However, only in the RE100% case, electrification cannot be observed due to considerable increase of electricity including the grid integration costs of VREs. Balanced electricity mix will be a key even for the CN.

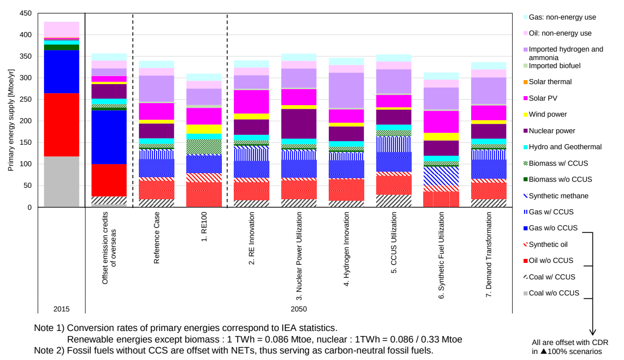

Figure 3 Primary energy supply in Japan for CN by 2050

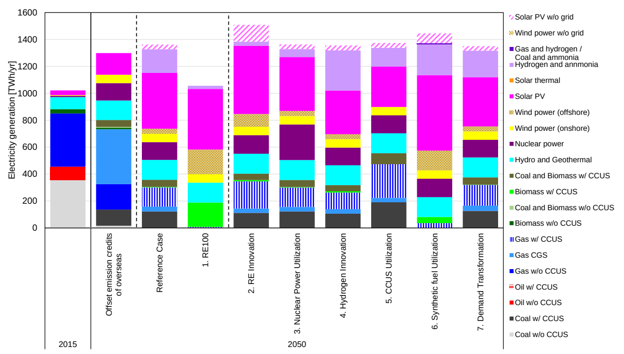

Figure 4 Electricity generation in Japan for CN by 2050

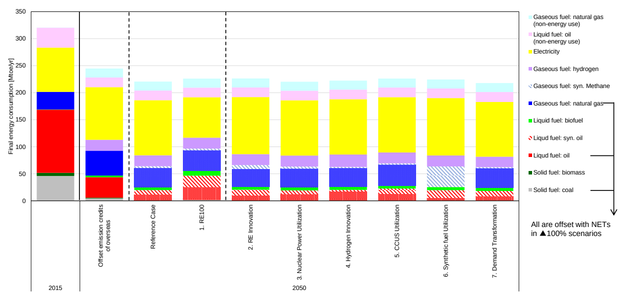

Figure 5 Final energy consumption in Japan for CN by 2050

In Figure 5, it can be observed that electrification in final energy is important, and hydrogen particularly for industry sector, synthetic liquid fuels for transport sector, and synthetic methane for building and a part of industry sectors will be cost-efficient for the CN in Japan. Meanwhile, considerable uses of natural gas will remain thanks to the emission offsets through DACCS.

CO_2 marginal abatement cost (carbon price) is estimated to be 168 $/t$CO_2$ in the globally least cost measure case for the 1.5 °C scenario ("Offset emission credits of overseas" case). On the other hand, the cost is estimated to be much larger and 525 $/t$CO_2$ in the Reference case which assumes to achieve the CN domestically. The costs can be reduced if several technological and social innovations are achieved, and it is necessary to seek the opportunities to induce innovations.

1.5. Implications from scenario analyses

DACCS will be able to play an important role under the CN as a back-stop technology. For achieving the CN internally, domestic DACCS will be also a cost-effective option. For achieving the CN in the world, it will be more cost-effective to deploy DACCS using affordable VREs and CO_2 storage potentials outside of Japan and offset the residue emissions of Japan through the emission credits. Since it is unclear that such options can work or not, the hedging strategy having several potential measures will be required. Hydrogen, ammonia, and synthetic fuels (synthetic methane and synthetic liquid fuels) are expensive options as well as DACCS, however, all of them can be the cost-effective options for the CN in Japan. The use of overseas resources should be also considered as the costs of VREs and CCU in Japan are high compared with those in some other countries. While VREs are highly important also in Japan, the grid integration costs as well as VREs are expected to increase according to large deployments of VREs. It is important to consider the whole energy systems including combinations of energy supply sources and energy demand-side measures as well as seeking the affordable emission reduction opportunities overseas.

All options should be pursued in order to achieve the CN as early as possible, as stated in the Sixth Strategic Energy Plan decided in October, 2021.

2. Evaluations on emission reduction efforts of the NDCs

2.1. Introduction

Under the Paris Agreement adopted at COP21 in 2015, all countries pledge nationally determined contributions (NDCs) for emission reduction targets after 2020 to the United Nations, and they are reviewed (Pledge and review). In 2015, the Systems Analysis group analyzed the emission reduction targets of the Intended Nationally Determined Contributions (INDCs) submitted before the adoption of the Paris Agreement based on various indicators (Reference 3), 4)).

By around the time of the leaders' summit on climate in April 2021, the emission reduction targets of NDCs had been raised, especially in developed countries. Japan deepened its emission reduction target, which was revised from the previous target of -26% (compared to 2013) in 2030, to -46%. Furthermore, Japan has declared to tackle to achieve -50% as a further ambitious goal. The Sixth Strategic Energy Plan was formulated, including the energy mix of Japan in response to its emission reduction target, and the plan for global warming countermeasures was revised (decided by the Cabinet in October 2021). On the other hand, China, India, and Russia have not deepened their emissions reduction targets. However, as China has the NDC target of CO_2 intensity of GDP and the outlook of GDP growth is lower than that estimated in 2015, the actual efforts on emissions reduction could be more ambitious than the expected efforts estimated in 2015.

Therefore, under the latest socioeconomic conditions including the impact of COVID-19 and their effects on baseline emissions, the emissions reduction efforts of the latest NDCs were evaluated by employing multiple indicators. The emissions reduction costs were estimated using a global assessment model for energy and climate change, namely DNE21+ model, which has been developed by the Systems Analysis Group. This study also assessed the interrelationship between the expected global emissions under NDCs and the long-term emission pathways for the 2 °C and 1.5 °C targets mentioned in the Paris Agreement, using the model (Reference 5)).

2.2. NDCs of major countries

Table 3 shows emissions reduction targets of the NDCs of major countries. Developed countries such as Japan, the United States, EU, and the United Kingdom have deepened their emissions reduction targets from those in the 2015 INDCs. However, since the base year for the reduction targets differs among countries, the emission reduction rates provided by each country should not be compared directly for measuring emissions reduction efforts. In addition, China and India serve CO_2 intensity targets, and some countries serve the targets of emissions reduction from their BAU emissions. To compare the emissions reduction rates based on the unified base year, it is necessary to convert the reduction rates which differ among the NDCs of countries to those unified in the specific base year. Figure 6 shows the unified rates of emissions reductions compared to 2013, which is the base year of Japan's NDC. Here, emissions in 2030 are calculated based on the historical records, the submitted emissions reduction targets, and the future GDP growth scenario for the countries having intensity targets. Compared to 2013, the UK has the lowest emissions among the major countries, followed by Switzerland and New Zealand. As discussed in Reference 3), the future population and economic outlooks vary across countries, and emissions reduction rates from the base year are estimated to be small in developing countries, whose economic growth rates are higher than in developed countries. Thus, even if the emissions reduction rates compared to the base year of developing countries are smaller than those of developed countries, it should not be necessarily evaluated that emissions reduction efforts are insufficient. Even for the comparisons of NDCs among developed countries, the emissions reduction rate compared to the base year will not be an appropriate indicator for measuring emission reduction efforts, because the historically cumulative efforts for emissions reduction differ across countries.

Table 3 Emission reduction targets of major countries

	Submitted emission reduction targets in 2030 of NDCs
Japan	-46% compared to 2013
United States	-50% to -52% compared to 2005
EU27	-55% compared to 1990
United Kingdom	-68% compared to 1990
Russia	-30% compared to 1990
China	-65% of CO_2/GDP compared to 2005
India	-33% to -35% of GHG/GDP compared to 2005

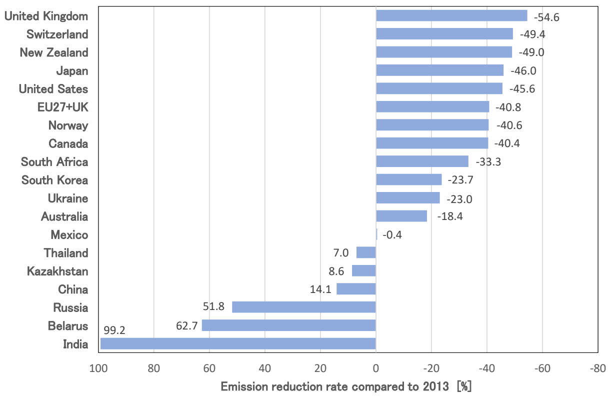

Figure 6 International comparison of emission reduction rate from the base year of 2005 for the NDCs

We also estimated emissions per capita, emissions per GDP, and emission reduction rate compared to BAU when the emission targets of NDCs are achieved. Emissions under BAU were estimated using the DNE21+ model.

2.3. Evaluations on emission reduction efforts of the NDCs using a global assessment model for energy and climate change

Figures 7 and 8 show international comparisons of CO_2 marginal abatement costs and emissions reduction costs per GDP, respectively. For Japan, the achievements of the power generation mix suggested in the Sixth Strategic Energy Plan (renewable energy: 38%, hydrogen/ammonia: 1%, nuclear power: 20%, LNG: 20%, coal: 19%, Oil: 2%) are assumed.

While the revised outlooks of production activities of several industries and transportation service demands were smaller than the previous ones including the impacts of COVID-19, many developed countries deepened their emission reduction targets as mentioned above. As a result, the estimated CO_2 marginal abatement costs and emissions reduction costs per GDP in many countries are higher than the previous estimates (Reference 4)). The CO_2 marginal abatement costs in New Zealand are very high (546 \$/tCO_2). Although the share of methane emissions in GHGs is high in New Zealand, the reduction potentials are limited according to the estimations by the US EPA, which are based on this study for the assessments of non-CO_2 GHG emission reduction measures. Therefore, significant emission reductions of energy-related CO_2 are needed, and the estimated marginal abatement costs rise considerably. If the emission reduction target of New Zealand is evaluated only for CO_2 emissions, the CO_2 marginal abatement costs are estimated to be 406 \$/tCO_2, which those costs are close to those of the United States and Canada. In particular, the estimations for land-use CO_2 and non-CO_2 GHG emission reduction costs are not easy, and careful treatments will be necessary.

Although China did not change the emission reduction target, allowable emissions are smaller than that in the previous estimation, because China has a CO_2 intensity target, and the outlook of GDP growth was changed downward. Then, the estimated CO_2 marginal abatement costs are higher than the previous estimates.

The emissions reduction costs per GDP include the impacts of net cost increase due to the decrease in export for fossil fuel exporting countries, and large increases in the costs can be observed in such countries like Russia.

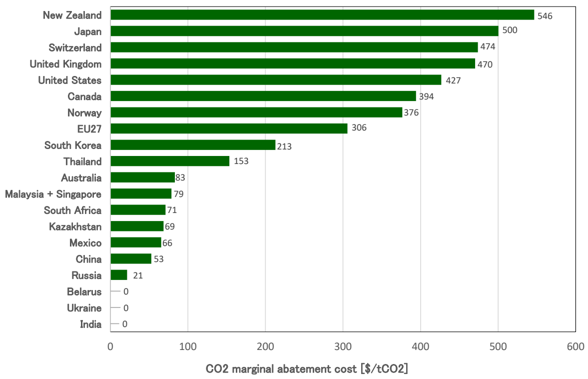

Figure 7 International comparison of CO_2 marginal abatement costs for the NDCs

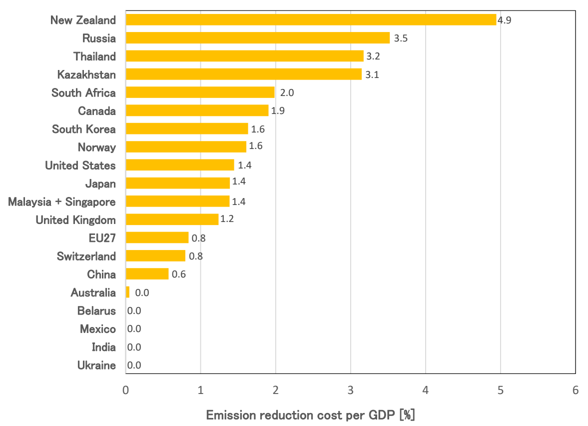

Figure 8 International comparison of emission reduction costs per GDP for the NDCs

2.4. Interrelationship between the expected global emissions in 2030 under NDCs and the long-term emission pathways for the 2 ℃ and 1.5 ℃ goals of the Paris Agreement

Figure 9 shows the global GHG emissions outlook under baseline up to 2050 (zero marginal abatement scenario), and the emissions in 2030 under the NDCs, as well as the emission pathways under 2 °C (>66%) and 1.5 °C (>66%).

The estimated global GHG emissions in 2030 under the NDCs are about 50 $GtCO_2$/yr, which are consistent with those estimated by UNEP. The UNEP report emphasizes the gap between the expected global emissions in 2030 under the NDCs and the long-term emission pathways for the 2 °C and 1.5 °C goals of the Paris Agreement. However, according to the cost-efficient emission pathways under the carbon budget constraints, the expected emissions in 2030 under the NDCs could be consistent with the emission level to meet the 2 °C or 1.5 °C goal, if a certain degree of temperature overshoot is allowed through the deployments of CDR such as DACCS. The emissions could be in line with cost-effective emission pathways if large deployments of CDR are feasible.

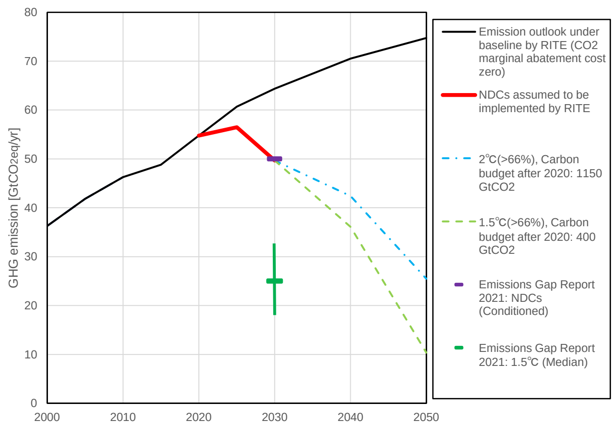

Figure 9 Expected global GHG emissions of the aggregated NDCs

2.5. Suggestions from NDCs emission reduction effort evaluation

The Paris Agreement employs a “pledge and review” type framework. Even recognizing the differences in capabilities across countries, it is important to seek the equitable efforts, in order to maintain the Paris framework and to achieve effective global emissions reductions. Our analysis suggests that the emissions reduction efforts even under the latest NDCs might still be huge differences among the countries, and continuous reviews for the NDCs will be required.

3. Analysis on economic impacts of Japanese NDCs in 2030

3.1. Introduction

This section focuses on the economic impacts of the emissions reduction targets in 2030. Using a global energy-economic model, we evaluated the economic impacts of the latest Japanese target of 46% emission reduction (compared to 2013) along with the energy mix of the latest (Sixth) Strategic Energy Plan for 2030 (Reference 7)). We compared the impacts of the -46% target with those of the previous target of -26% based on the previous (Fifth) Strategic Energy Plan.

3.2. Methodology

The global energy-economic model, DEARS, which is used for this analysis, has a structure of dividing the world into 18 regions and integrating a top-down economic module and a bottom-up energy system module. The model is formulated as having an objective function of discounted global consumption utilities. The economic module has a computational general equilibrium modeling structure with an international input-output table based on the database of GTAP (global trade analysis project, Reference 8)) ver.9, representing industrial and trade structures by region and by sector. The energy system module represents simplified energy system flows explicitly and can deal with the constraints of the energy mix.

We assumed the baseline GDP (with average annual growth rate of 1.4%/year for 2010-2030 in Japan) based on "Economic and Fiscal Projections for Medium to Long Term Analysis" published by the Cabinet Office of Government of Japan in July 2021, considering COVID-19 impacts partially. We assumed the CO_2 emissions in 2020 with zero carbon price and considered the COVID-19 influences through the GDP assumptions.

The energy mix of the power sector in Japan in the baseline is assumed to be constant with that in 2019. The composition of the energy mix under the 46% reduction target in 2030 is assumed to be 19% for coal power, 20% for LNG power, and 2% for oil power; 16% for PV, 15% for wind (with 10 GW for offshore), 12% for hydro and geothermal, and 20% for nuclear power. The costs in the power sector were reflected based on the Power Generation Costs Analysis Working Group[9]. The unit costs of new power generation were assumed based on the lists of each power source, assuming an annual discount rate of 5%. The integration costs related to VRE were also based on the "estimation without considering power source location and grid constraints" (Reference 9)). The NDCs targets of the U.S and EU in 2030 were assumed to be 50% reduction (compared to 2005) and 55% reduction (compared to 1990), respectively.

3.3. Results

Figure 10 shows the GDP changes for the 26% and 46% reduction targets, respectively, to compare the macro-economic impacts between the previous and new targets. The estimated GDP change for the 46% target in 2030 is relatively large at 4.2% decrease (relative to the baseline) while at 0.5% decrease in the 26% target. The carbon prices required for the 26% and 46% reduction targets are estimated at 105 and 534 $/tCO$_2$, respectively. In the 46% reduction case, although there is a positive effect of increased investment in low-carbon energy, the GDP is estimated to decline due to decreases in net exports and consumption. The net export decreases represent worsening international competitive conditions, mainly in the manufacturing sector, deteriorating relative prices. The consumption decreases result from price increases of goods and services caused by extension of energy price increases for the reduction target.

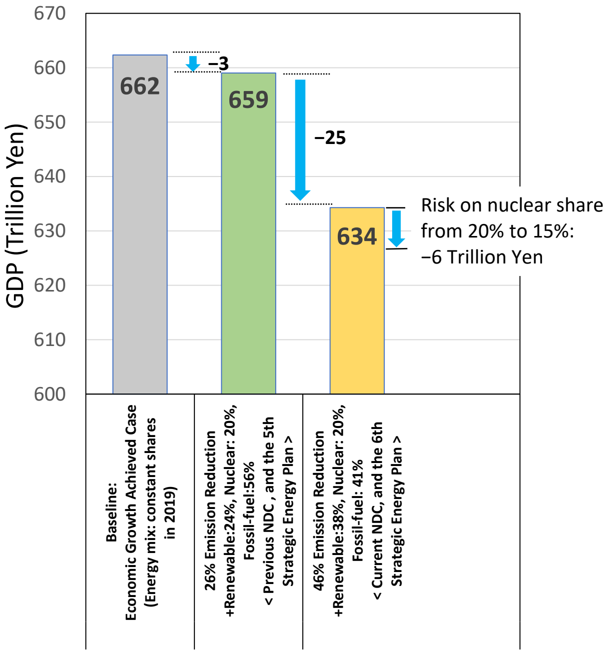

Figure 10 Real GDP in Japan(2030)

The GDP loss and CO_2 marginal abatement cost (carbon price) estimated in this study are smaller than the previous estimates (Reference 10)) even in the same 26% reduction target. This is because the previous estimation assumed the higher baseline GDP at about +0.2%/year of annual growth rate for 2010-2030 than this analysis and the higher cost of renewable energy generation.

Figure 11 shows sectoral production changes for the 26% and 46% reduction targets. The production changes in the energy-intensive and trade-exposed sectors such as iron & steel and chemical have adverse impacts at about 12-14% decreases (relative to the baseline), more significant than GDP changes corresponding to the sectoral average.

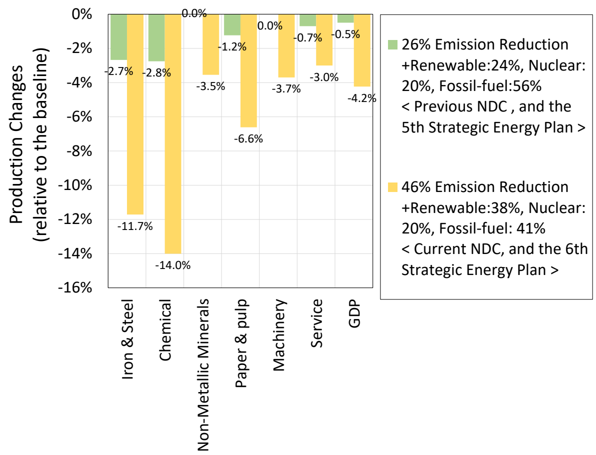

Figure 11 Changes in sectoral production (Japan, 2030)

Figure 12 shows the potential changes in electricity bills for the 26% and 46% reduction targets. The "effects of carbon price" in the figure stand for price impacts due to the penalty against the fossil-fuel power plants to carbon prices required for the reduction targets under implementations of the energy mix. The electricity expenditure in the 46% reduction target is estimated larger than that in the 26% target. It results from cost increases by carbon prices in the 46% target rather than the energy mix.

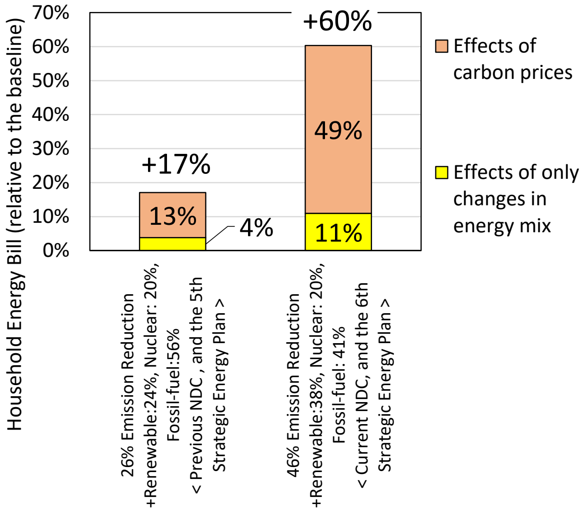

Figure 12 Impacts of household electricity bill (Japan, 2030)

Figure 13 shows the GDP losses with sensitivity analysis to the emissions reduction levels with shares of renewable and fossil fuels in the power generation. The GDP losses increase substantially when the emission reduction level changes from 35% to 46%. The result indicates that in the stringent targets, the potentials for mitigation measures on the energy supply side becomes smaller, and the need to respond to measures on the demand side, including the decreases in production activities, becomes larger.

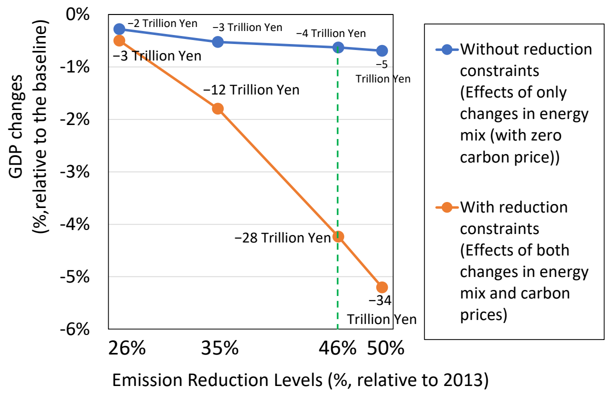

Figure 13 GDP impacts of emission reduction levels and shares of renewables/fossil-fuels

Note: In all the cases, share of 20% for nuclear power was assumed. The energy mix for 35% and 50% reduction levels were assumed to be interpolated and extrapolated using shares of the Fifth and Sixth Strategic Energy Plans, respectively.

3.4. Summary of economic impact analysis on the NDCs

The Japanese government raised the emissions reduction target for 2030 to 46% in response to calls for stronger actions for climate change mitigation both domestically and internationally. The estimated impact is about 4% GDP loss (relative to the baseline). Although investments for low-carbon energy increase, adverse consequences of trade and consumption are significant, resulting in decreases in net exports due to worsening competitive conditions and decreases in household consumption due to rising prices of goods and services. In the manufacturing sector, which is energy-intensive and vulnerable to international competition, such as the steel and chemical industries, the decline in output is expected to be considerably more significant than the GDP loss. In the household sector, the results also indicate the possibility of a substantial increase in household electricity and energy bills.

In this analysis, the solutions after achieving equilibrium are presented by the CGE (computation general equilibrium)-typed model. It should be noted that in the real transition processes, the adverse effects may be more severe in specific industries. In addition, since the difference in national/regional carbon prices required for achieving the NDCs is estimated to be extremely large (see the previous section), the impacts based on price elasticities will possibly work discontinuously in specific industries. The sufficient care for such industries should be taken in interpreting the results.

The international political and business environment, including the finance side, strongly encourages the commitment to more ambitious and stringent emission reduction targets, making it essential to strengthen efforts to address climate change. On the other hand, the 46% reduction target potentially has the risk of significant adverse impacts on the economy. This result indicates the importance of promoting appropriate transitions with inducing social and technological innovations.

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