Economic impacts of power supply and CO2 emission reductions of Japan after the Fukushima nuclear power accident

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Abstract

This paper discusses the energy strategies of Japan after the severe accident of the Fukushima-daiichi nuclear power plant. Firstly, this paper presents the economic analyses of the three options of “Options for Energy and Environment”, proposed by the Energy and Environmental Council of the Japanese government. The three options are the scenarios where the shares of nuclear power generations are 0%, 15% and 20-25% in 2030. All the options include the stringent CO2 emission reductions of 21-25% in 2030 relative to 1990.
This paper presents the quantitative analysis on economic impacts of Japan by sector in 2020 and 2030 for CO2 emission reduction targets on the consideration of international industrial relationships using DEARS (Dynamic Energy-economic Analysis model with multi-Regions and multi-Sectors). DEARS model is a dynamic optimization model, which maximizes global discounted consumption utilities and evaluates the impacts of CO2 emissions reduction policies on energy and economic systems. DEARS has two modules. One is the economic module which represents explicitly industrial structures of production, consumption and trade by region and by sector, which are required for sectoral analysis on climate policies. The other is the simplified energy systems module which represents explicitly energy flows. The two modules are completely linked. The model includes 18 regions and 18 non-energy sectors. The model also includes eleven energy sources with seven types of primary energy (coal, crude oil, natural gas, biomass, hydro power, wind power, and nuclear power) and four types of secondary powers (solid, liquid, and gaseous fuels and electricity), where energy supply technology and CCS (carbon dioxide capture and storage) technology are considered. The main datasets of DEARS are based on GTAP database for economic systems and IEA statistics and other sources for energy systems. The baseline scenario for GDP and population

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is based on the government scenarios. The baseline GDP growth rates of Japan are harmonized to be are 1.1%/year and 0.8%/year for 2010-2020 and 2020-2030, respectively. The population of Japan in 2010 and 2030 in the baseline are 121 and 117 million peoples, respectively, which are exogenous variables in the model. The model baseline of final energy consumptions is calculated endogenously within the model, but is also harmonized with the Japanese government scenario for the analyses of the "Options for Energy and Environment". The costs of electricity generations by energy source are based on the estimations by the Committee for Verifying Power Plant Costs of Energy and Environment Council of the Japanese government. The DEARS model can reflect these costs because the model has the bottom-up structures of the energy sector. From the simulation results, the GDP losses in all the three scenarios are beyond 4% relative to the reference case while the marginal abatement costs are beyond $400 per ton of CO2. Within the options, the economic impacts are significantly severe in the case of nuclear power of 0% in 2030, where the GDP losses are 7.4% and the marginal abatement costs are $470-640 per ton of CO2. However, these analyses on the options are at least three controversial issues. The first is the drastic energy savings. Even in the baseline, these assumptions are greatly inconsistent with the historical trends in Japan and other countries although the strong correlations between growths of GDP and power demands were historically observed. The second is the considerable increases in renewable energies. In all the options, the shares of renewable energy power generations are beyond 25%. The third is the deep CO2 emission reductions targets. In terms of marginal abatement costs, the reductions targets of all the options are much larger than those of the literature on economic analysis for other countries such as IEA-WEO. In order to improve these issues, we assume the revised baseline with higher consistency between economic growths and electricity consumptions than the assumptions in the "Options for Energy and Environment" by the Japanese government. The revised GDP growth rate of Japan for 2010-2030 in the baseline is 1.3%/year. We also assume the alternative options with more modest extensions of renewable energies and with the moderate levels of the CO2 emission reductions, where the marginal abatement costs in 2030 are about $150 per ton of CO2. These reductions levels are higher than those of the literature on economic analysis for other countries, but lower than those of "Options for Energy and Environment" by the government. The analysis on economic impacts of the alternatives are performed. Our results reveal that the GDP losses in 2030 are within about 2% relative to the revised baseline, where the economic growths can reach the government's growth scenario of 1.0%/year for 2010-2030. These analyses help further discussions on a more realistic strategy.
Keywords: Climate Change; Economic analysis; Energy mix

1. Introduction

Reviews of Japan’s energy and environment strategy have been required after the severe accident of the Fukushima Daiichi nuclear power plant resulting from the Great East Japan Earthquake and Tsunami of March 11, 2011. Based on many discussions on strategy reform in several committees established by the Japanese government, plural “Options for Energy and the Environment” were developed by the Energy and Environment Council (2012a). We analyzed economic impacts of the “Options for Energy and the Environment” using an energy-economy model.

The Energy and Environment Council (2012a) of the Japanese government proposed the “Options for Energy and the Environment” with the results of analysis of economic impacts for each option on June 29, 2012, and wide-ranging discussions were held with the public. After these discussions, the government’s Energy and Environment Council (2012b) approved the “Innovative Strategy for Energy and the Environment” on September 14, 2012. The report on the strategy stated that “all policy resources will be utilized to make possible the achievement of zero nuclear power generation in the 2030s.” The report was submitted to the National Strategy Council on September 18, but no final decisions on the report were made by the council. The previous cabinet council did not provide any final approval for the “Innovative Strategy for Energy and the Environment”, either, although it did approve only a short sentence regarding future plans for energy and environment strategy.

In order to tackle global warming issue, the “Innovative Strategy for Energy and the Environment” states that “strong promotion of energy efficiency improvements and renewable energy increases both domestically and abroad correspond to global warming response measures. Greenhouse gas emission reductions will be promoted with the strong support of the government from a long-term viewpoint.”

The cause of the severe nuclear power plant accident remains obscure, and it is difficult to establish a clear middle- and long-term energy strategy. The difficult issue of how to balance the “3Es” of stable energy supply and energy security, economy, and environment remain. Further considerations, including achievability, are required, taking economic impacts into account.

The remainder of this paper proceeds as follows. Section 2 outlines the energy-economic model used for economic analyses in this study. Section 3 reviews the “Options for Energy and the Environment”. Section 4 describes an analysis of economic impacts of the “Options for Energy and the Environment”. Section 5 explains the outlooks for electricity demand in the baseline, revised assumptions based on such outlooks, and economic analysis on alternative options. Finally, Section 6 provides a conclusion.

2. World energy-economic model: DEARS

In order to analyze economic impacts on Japan of energy and CO_2 emission reduction strategies after the severe accident of the Fukushima Daiichi nuclear power plant, we utilize a world energy-economic model known as DEARS (Dynamic Energy-economic Analysis model with multi-Regions and multi-Sectors). DEARS is an intertemporal optimization model, which maximizes global discounted consumption utilities up to the middle of this century with ten-year steps and a computable general equilibrium (CGE) model. The model evaluates the impacts of energy and CO_2 emissions reduction policies on economic systems with consideration of international industrial relationships.

DEARS has two modules. One is the economic module, which represents explicitly industrial structures of production, consumption, and trade by region and by sector in terms of monetary units, which are required for sectoral analysis on climate policies. The other is the simplified energy systems module, which represents explicitly energy flows in terms of physical units.

The two modules are completely linked (see Figure 1). The model includes 18 regions and 18 non-energy sectors, according to Tables 1 and 2. Figure 2 shows nested model structures in the non-energy sectors. The macro production functions for the whole economy are based on the Cobb-Douglas function, while the sectoral production functions for the non-energy sectors are based on the Leontief function. The model also includes twelve energy sources with eight types of primary energy (coal, crude oil, natural gas, biomass, hydro power, wind power, nuclear power, and photovoltaics) and four types of secondary powers (solid, liquid, and gaseous fuels, and electricity). These various types of electricity generation and carbon dioxide capture and storage (CCS) technology are modeled. CCS technology was excluded from this study, including the mitigation evaluations up to 2030. The model has bottom-up modeling structures for these technologies. Although the model originally employed fossil fuel resource and production costs assumptions derived from the estimations of Rogner (1997), this study is based on the fossil fuel prices provided by the government. The energy-saving effects are evaluated using long-term price elasticity.

The main datasets of DEARS are based on the GTAP database (Hertel (1997), Dinaranan (2006), Alexander (2008)) for economic systems and on IEA energy balances and datasets of other models (Akimoto et al. (2010), RITE (2009)) for energy systems. Since the input-output table is based on GTAP, which is commonly used for international CGE model analysis, the international transfer of industry (leakage of industry) can be analyzed.

Since the information on the energy supply and the power generation sector is not sufficient in the input-output table, we conduct bottom-up modeling taking relevant technologies into account and make adjustments to achieve consistency with IEA statistics, which allows consistent analyses and assessments of energy and the economy. Such bottom-up modeling is able to analyze economic impacts with full consideration of differences in electricity generation costs by fuel, which have been provided by the Committee for Verifying Power Plant Costs (Energy and Environment Council, 2012c), and in power generation mix by option.

Table 1 Regional dimension of the DEARS model

Developed regions		Developing regions	
JPN	Japan	CAM	Central America
USA	U.S.A.	BRA	Brazil
CAN	Canada	SAM	Other Latin America
WEP	Western Europe	CHN	China
EEP	Eastern Europe	IND	India
FSU	Former Soviet Union	ASN	ASEAN
		TME	Middle East
		NAF	Northern Africa
		CAF	Central Africa
		SAF	Southern Africa
		ROW	Rest of the world

Table 2 Sectoral dimension (non-energy) of the DEARS model

I_S	Iron and steel	LUM	Lumber
CRP	Chemical	CNS	Construction
NFM	Non-ferrous metal	TWL	Textile
NMM	Non-metal mineral	OMF	Other manufacturing
PPP	Paper and pulp	AGR	Agriculture
TRN	Transport equipment	ATP	Aviation
OME	Machinery	T_T	Other transport
OMN	Mining	BSR	Business service
FRP	Food processing	SSR	Social service

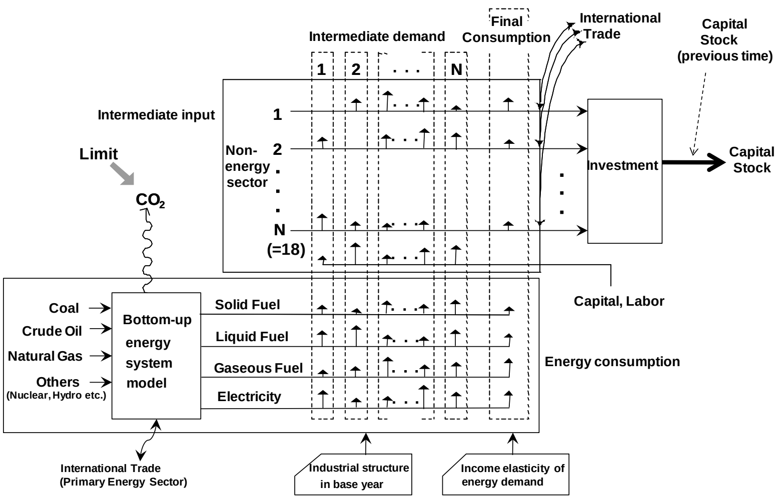

Figure 2 Intergation of top-down (economic systems) and bottom-up (energy systems) in DEARS

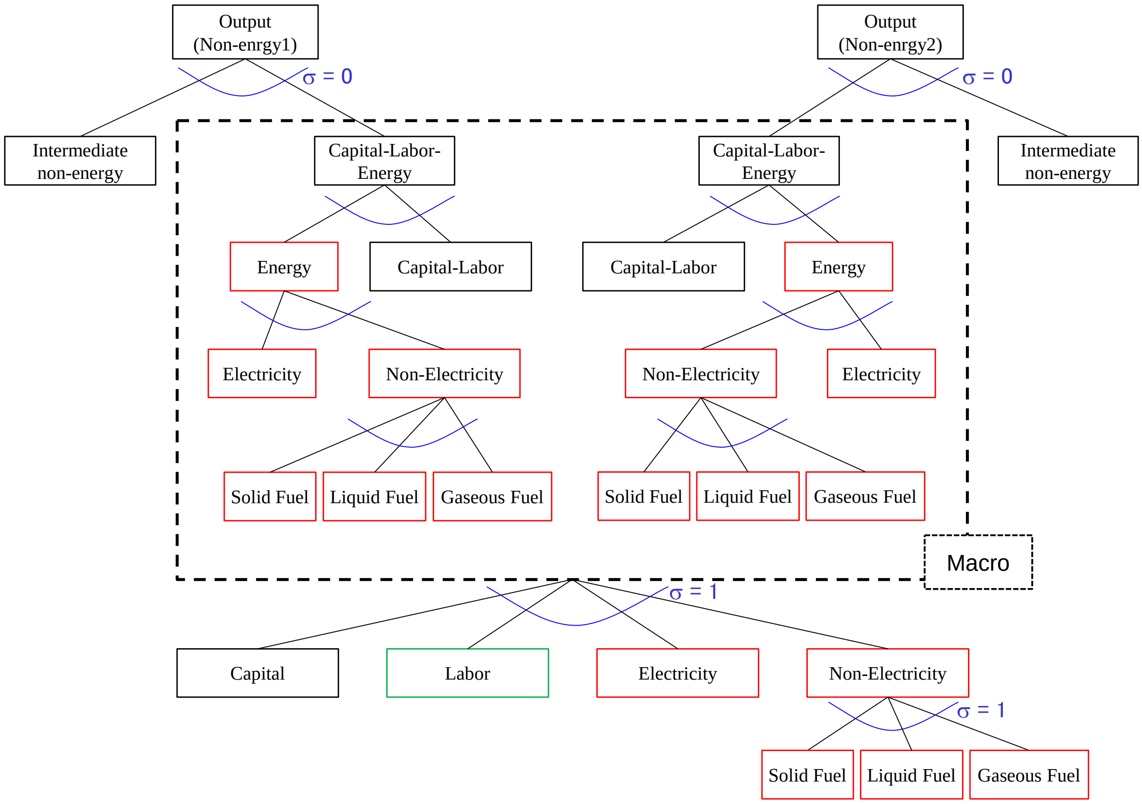

Figure 1 Structure of non-energy sector in DEARS

Note: For simplicity, only 2 non-energy sectors are depicted in the figure. The 18 non-energy sectors are practically modeled.

3. Overview of the Options for Energy and the Environment

This chapter summarizes the "Options for Energy and the Environment" provided by the Japanese government. The following three options, particularly based on dependences on nuclear energy, were presented by the Energy and Environment Council.

Option 1 is a "0% nuclear power" scenario of achieving zero nuclear power generation by 2030, where the electricity supply shares of renewable energy and fossil fuels are about 35% and 65%, respectively. PV systems are installed in 12 million houses by 2030, where even if the houses have low earthquake-resistance strengths, they are reinforced against earthquakes, following which PV systems are installed therein. Wind power plants are built in for a total area that would be 2.2 times as large as the Tokyo metropolitan area. Strict regulations for energy savings, such as the prohibition of inefficient electric appliances, are also introduced in this option.

Option 2 is a "15% nuclear power" scenario of achieving a 15% nuclear power generation share by 2030, where nuclear plants are operated within a 40-year period and no new nuclear plants are built during such period. In this option, the electricity supply share of renewable energy is about 30%. PV systems are installed in 10 million houses, all of which satisfy the standards for earthquake-resistance strength. Wind power plants are built for a total area that would be 1.6 times as large as the Tokyo metropolitan area. The share of fossil fuel power generation is about 55%.

Option 3 is a “20%–25% nuclear power” scenario of achieving a nuclear power generation share of about 20%–25% by 2030, where the electricity supply shares for renewable energy and fossil fuels are about 25%–30% and 50%, respectively. This option requires new and additional facilities for nuclear power generation by 2030. Through continuous efforts for the enhancement of the safety and security of nuclear power, improvements in the currently negative public opinion of nuclear power are important for achieving this option.

The determined “Innovative Strategy for Energy and Environment” (Energy and Environment Council, 2012b) describes a power generation mix for 2030 close to that of the “15% nuclear power scenario.” However, substantially because the determined strategy brings zero nuclear power generation in specific target years into view, the strategy is qualitatively similar to the “0% nuclear power scenario.”

The economic impacts of each option were estimated using four energy-economic models of four research institutes in accordance with an official government request. The DEARS model is one of them, and the other economic models are single-country models focusing on Japan. The DEARS model uses 18 disaggregated world regions including Japan, which allows it to explicitly evaluate the impacts of international sectoral shifts among such 18 regions thorough increases in energy prices and the intensities of the CO_2 emission constraints in Japan. In addition, the model can reflect the power generation costs by energy source thanks to bottom-up modeling for power generation by fuel, as does the KEO model (Kuroda and Nomura (2001); Kuroda et al. (1995)), which was also used to conduct the economic analysis at the request of the government. This paper describes outlooks for the economy and CO_2 emission reductions for the three options, based on the results of the DEARS model.

Table 3 shows the main assumptions of the options for economic analyses, as requested by the Japanese government. Social and economic factors such as population and GDP are based on the “Prudent Scenario” provided by the Cabinet Office of Japan (2012).

Table 3 Assumptions of economic analysis for the options of the Energy and Environment Council

	Reference case (Business as usual: BAU)	NUC 0%	NUC 15%	NUC 20–25%	
				NUC 20%	NUC 25%
Population	2010: 128 million people; 2020: 124 million people; 2030: 117 million people				
GDP	2010-2020: 1.1 p.a. 2020-2030: 0.8 p.a.	Calculated endogenously in the model			

Electricity share (2030)	Keeping the shares of 2010	Nuclear 0% Fossil fuel 62% Renewable 38%	Nuclear 15% Fossil fuel 54% Renewable 31%	Nuclear 20% Fossil fuel 48% Renewable 31%	Nuclear 25% Fossil fuel 48% Renewable26%
Power generation	2010-2030: +0.15 p.a.	Calculated endogenously in the model (Electricity demands change based on differences of electricity prices on the assumptions of both electricity shares and CO_2 emission reductions for each option)			
Energy-related CO_2 emissions (compared to 1990) 2020 2030	+2% −6%	−2% −21%	−5% −22%	−6% −25%	−7% −25%
GHG emissions (compared to 1990) 2020 2030	— —	−7% −23%	−9% −23%	−10% −25%	

Figures 2 show electricity generation for each option in 2030. Here, there are four important points about the assumptions of the options, described as follows. The first point is that large potential for electricity savings is assumed in every option. Even in the current Basic Energy Plan (METI, 2010), the estimated power generation in 2030 was about 1200 TWh, while large potential for energy savings was assumed. However, the assumed potential for energy savings in each option is much larger than that of the current Basic Energy Plan. This point will be examined in greater detail in Section 5.

The second point is that all the options assume the large increases in renewable energy. The current share of renewable energy in electricity generation is about 10% (as of 2010), and excluding hydro power the share of other forms of renewable energy is only 2%. However, even the 25% nuclear power scenario assumes a renewable energy share of about 25% in 2030. The renewable energy share reaches about 35% in the 0% nuclear power scenario.

The third point is that considerable increases in auto producer power plants and cogeneration are assumed. These increases are important particularly under electricity shortages after 3.11. However, the currently low levels of cogeneration diffusion in Japan are explained by reasoning that the cogeneration systems are not well linked to heat demand in Japan and the distributed cogeneration systems are still expensive.

The fourth point is that electricity shares with low capacity factors are assumed. This is because of the outlooks for both increases in renewable energy power plants with low capacity factors and considerable decreases in electricity demand. The low capacity factors also result from increases in non-operating fossil fuel thermal power plants because of the rapid changes in electricity shares. As low capacity factors result in high costs, the scenarios with the low factors assume inefficient usage of plants.

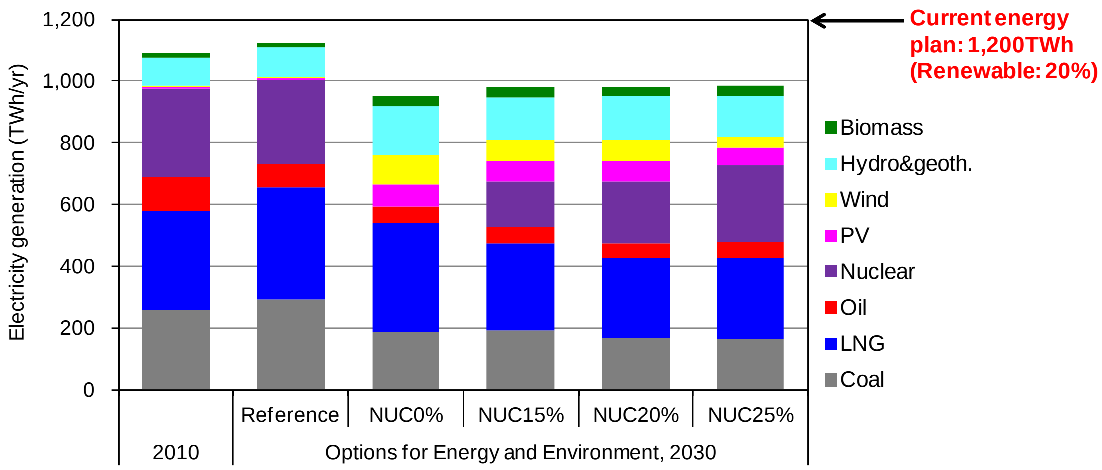

Figure 2　Electricity generation scenarios in 2030 for each option

4. Economic analysis of "Options of Energy and the Environment"

The economic analysis of the "Options for Energy and the Environment" include the following three steps. Firstly, we start with the computation of the reference case. In the reference case, by adjusting parameters of the model such as total factor productivity, the model reproduced the government's assumptions in a manner that was consistent with endogenous variables such as GDP, household consumption expenditure, electricity generation, and CO_2 emissions. For the analysis, the DEARS model adopts figures for current and future costs of power generation by source and fuel costs by source that were provided by the Committee for Verifying Power Plant Costs in the Energy and Environment Council of the Japanese government (2012c). Secondly, we carried out the analysis under the assumed different shares for power generation source for each option without CO_2 emission constraints. Finally, we performed analysis for the options with the assumed CO_2 emission constraints of each option.

We analyzed the economic impacts of the options using model parameters adjusted for the baseline, under the constraints of the electricity shares and the CO_2 emission targets for the options. The total power generation values assumed by the government, which are shown in Figure 2, were not employed for the constraints of the DEARS model. Alternatively, the CO_2 emissions constraints were employed. Total electricity generation was determined endogenously in the model. Thus, the electricity generation in the baseline is harmonized with the government's assumptions but those in the options are not necessarily harmonized with the assumptions as shown in Figure 1. On the other hand, the electricity shares by energy source in the model are identical to the government's assumptions for the baseline and all the options.

4.1. Impacts on electricity and fuel charges in the household sector

Figures 3 and 4 show estimated electricity and fuel charges in the household sector in 2030 and 2020, respectively. The results without CO_2 emission constraints correspond to impacts only from differences in power generation mix. In 2030, even in the 25% nuclear power scenario, the energy prices increase by +11% compared to the baseline, which assumes the same electricity share by fuel as that for 2010, mainly because the shares of renewable energy increase. The prices for the 15% and 0% nuclear power scenarios increase by +21% and +26%, respectively. These price increases are expected to lead to electricity savings. However, more electricity savings are required for achieving the assumed CO_2 emission reductions targets of each option. In order to achieve the targets, the energy prices are required to increase by +80% and the estimated electricity charges increase by 69% in the 0% nuclear power scenario, where the electricity prices are required to increase by +122%. The increases in the electricity and fuel charges are lower than those in the prices, because these price increases result in additional energy savings. Nevertheless, the electricity and fuel charges in the hosehold will be required to increase by 69% in the 0% nuclear power scenario. As shown in the Figure 5, the changes in electricity and fuel charges are lower than those in 2030.

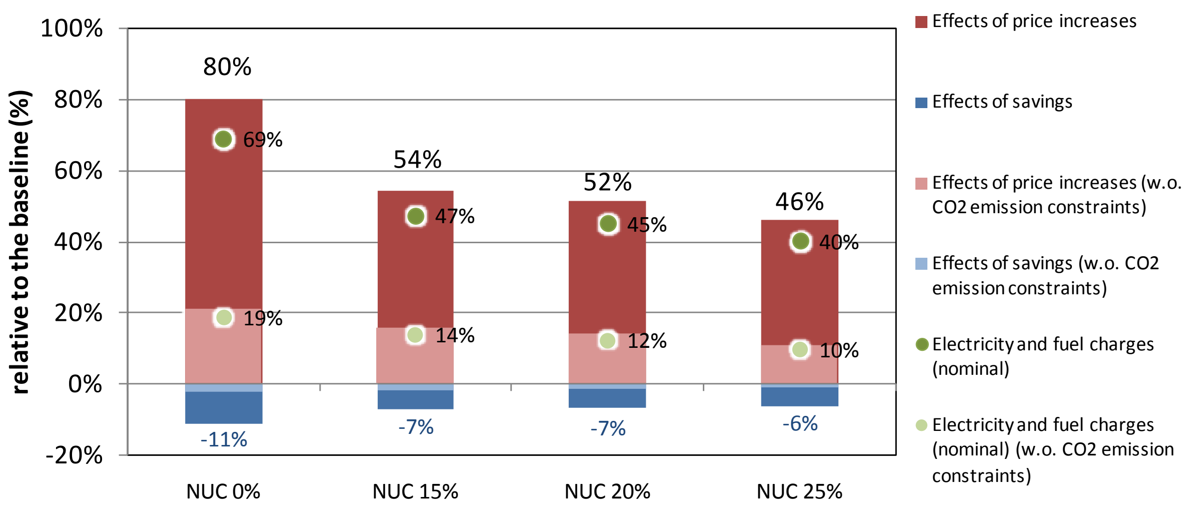

Figure 3 Electricity and fuel charges in the household sector in 2030, including the effects of energy price increases and energy savings

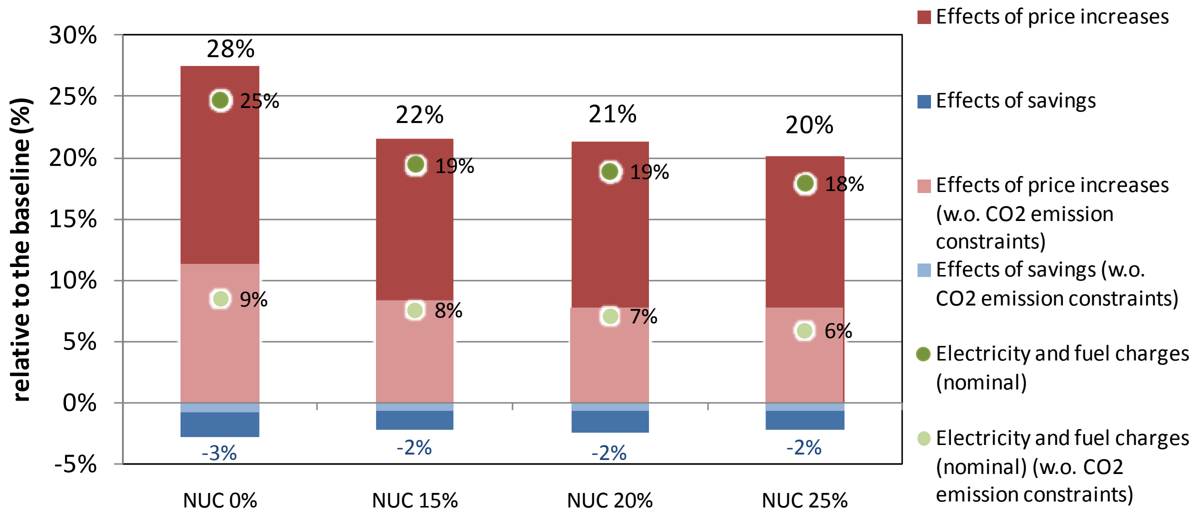

Figure 4 Electricity and fuel charges in the household sector in 2020, including the effects of energy price increases and energy savings

4.2. Macroeconomic impacts and costs of CO2 emission reduction

The increases in domestic energy prices induce consumption decreases. The increases in industrial electricity price result in price increases for several goods and services, and decrease companies' profits and investments. Figure 5 shows the impacts on the economy as a whole for each option. The results reveal that GDPs in 2030 scenarios of nuclear power shares between 15% and 25% decrease by 4.4%–4.9% relative to the reference case. On the other hand, the GDP loss in the 0% nuclear power scenario is much larger, with the GDP decreasing by 7.4%. Because stringent energy savings and great increases in renewable energy are assumed in all the options, large economic impacts are estimated. In addition, the results indicate that the smaller the assumed share of nuclear power generation, the larger the estimated economic damage. The economic damage in the 0% nuclear power scenario is particularly severe.

Decreases in consumption are larger as well as those in GDP. The smaller dependtence ratios of nuclear power result in the larger decreases in consumption. On the other hand, the decreases in investment are smaller than those in GDP and consumption. This is because the additional investments are required in order to reach the CO_2 emission reductions targets where other investments for economic growths are decreased. In particular, in the nuclear zero scenario, much smaller decreases in investment are estimated because of the required investments such as renewable energy costs, grid system integration costs for renewable energy and additional costs for rapid phase-out of nuclear plants.

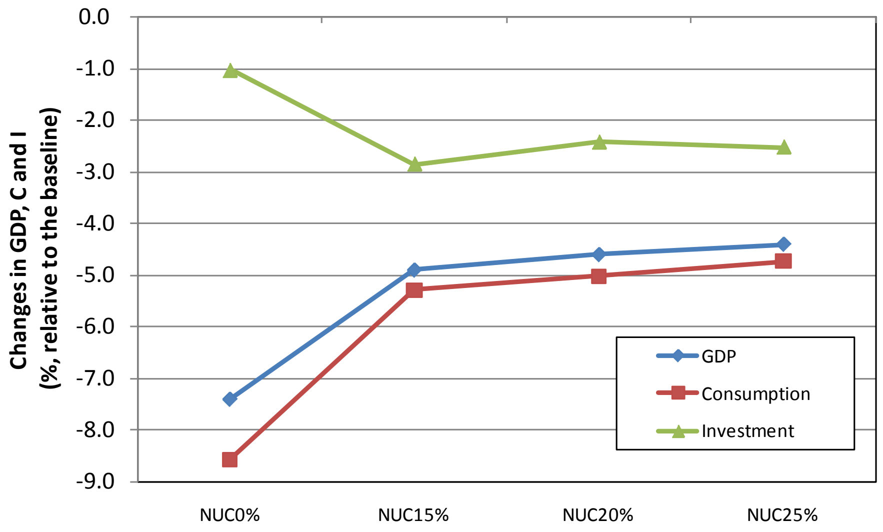

Figure 5 Impacts on GDP, consumption and investment in 2030

In the case that CO_2 emission reduction targets are excluded from all options, the economic impacts are much smaller than those with the assumed CO_2 emission reduction targets. The impacts of CO_2 emission reduction targets assumed by the government are much larger than those of the nuclear power shares, although the impacts of nuclear power shares are not small. However, CO_2 emissions differ widely among the options in the cases that do not assume CO_2 emission targets. For example, CO_2 emissions in 2030 are 11% relative to 1990 in the 0% nuclear power scenario, while the figure is 18% in the 25% nuclear power scenario.

The assumed GHG emission reductions in 2030 in the three options of the "Options for Energy and the Environment" are 23%–25% relative to the 1990 level. The "Innovative Strategy for Energy and the Environment" (Energy and Environment Council, 2012b) states that the target for Japanese GHG emissions in 2030 is a decrease by about 20% compared to 1990 emission levels.

The CO_2 marginal abatement costs for the reduction targets of 23%–25% in the options are about 39 and 40–41 thousand yen per ton of CO_2 in the 15% and 20%–25% nuclear power scenarios. In the 0% nuclear power scenario, the costs reach about 55 thousand yen per ton of CO_2 because greater enhancements of energy savings are assumed in this scenario.

On the other hand, the international levels of carbon prices are around \$30–\$50 per ton of CO_2 by 2030, estimated by several previous studies. For example, according to the EU (2011), the outlooks for carbon prices in the EU are €36–€62 per ton of CO_2 in 2030 for a GHG reduction of about 40% relative to the 1990 level. According to the World Energy Outlook by IEA (2011), the estimated prices in 2030 are \$40 per ton of CO_2 in the new policies scenario. The estimated carbon prices for all the options provided by the Japanese government reach about ten times as high as the international figures. Such high carbon prices will induce the decreases in domestic production and consumption. The significant differences in the prices between Japan and other countries facilitate overseas shifts of Japanese industry, particularly in energy-intensive sectors (see, Figure 6). These shifts do not necessarily decrease global CO_2 emissions. For example, in the iron and steel sector, the global emissions in the 0% nuclear power scenario increase by +0.46% (relative to the reference case) regardless of emission reductions in Japan. (All of the analyses with the DEARS model conducted in this paper assumed around $40 per ton of CO_2 in 2030 for carbon prices in all countries excluding Japan.) Helm (2011) reported that in the UK case, although production-related carbon fell by about 15% between 1990 and 2005, consumption-related carbon, including carbon imports, actually increased by around 19% in this period. This indicates while production of energy- or carbon-intensive commodities in a country decreases because of emission reductions targets, imports of such commodities (for example, from developing regions) increase with lower energy efficiencies.

CO_2 emission reductions are very important for the mitigation of global warming; however, there are large economic impacts of the deep emission reductions that would occur in a scenario in which nuclear power expansion would be difficult. How to balance economic impacts, nuclear power shares, and CO_2 emission reductions will be a key point for policy making.

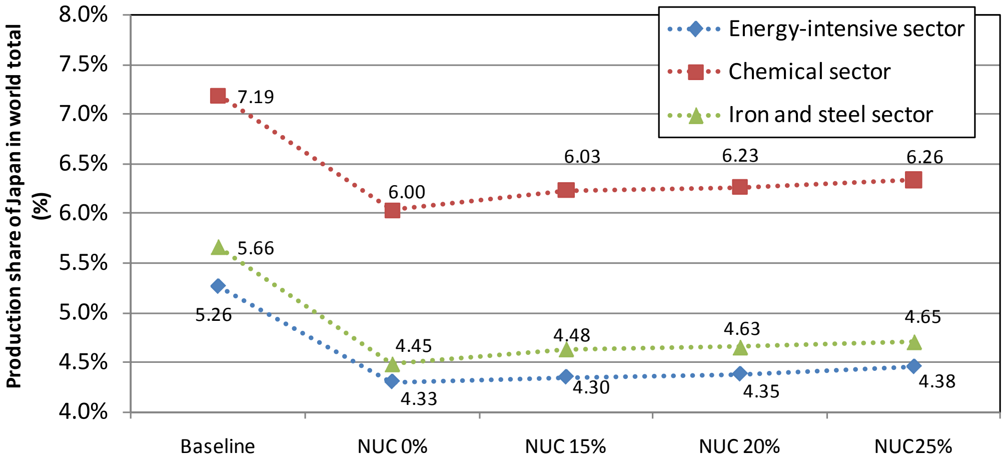

Figure 6 Production share of Japan in world total in 2030

5. Outlooks for electricity savings in the "Options for Energy and the Environment" and economic analysis under the revised assumptions

5.1. Outlooks for electricity savings

Strong positive relationships between growth of GDP and power generation in Japan can be observed, as demonstrated in Figure 7. The GDP elasticity of power generation was just 1.0

for 2000–2010 in Japan. The elasticity during 1990–2010 was higher. As mentioned previously, the government's options assume an economic growth rate of about 1% per year between 2010 and 2030. This assumption leads to GDP increases by 2030 of +21% compared to 2010. If GDP elasticity of 1.0, which corresponds to the historical trend during the previous ten years, is adopted for the outlook of the future electricity demand, assumed electricity generation will increase by +21% by 2030. However, the increase in electricity generation estimated by the government is only 3% in the reference case. Thus, the "Options for Energy and the Environment" assume extensive energy and electricity savings without any solid evidence. These assumptions of energy and electricity savings are excluded from assessments of economic impacts by the economic model. This involves the assumption that the power generation changes from +21% to +3% relative to 2010 can be achieved without economic damages.

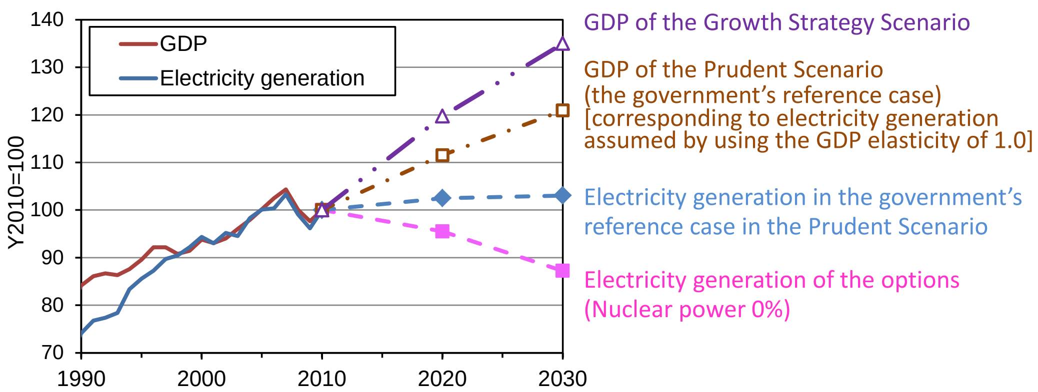

Figure 7 Historical trends and government assumptions of GDP and electricity generation

Energy and electricity savings greatly improved after the Fukushima nuclear power plant accident. It was reported that the national average of the electricity savings during the summer (July and August) of 2012, for example, reached about 6% in terms of kWh (estimated by the Agency for Natural Resources and Energy in the Energy and Environment Council (2012d), including the corrections for climate and economic conditions). However, currently, the economic impacts of the aforementioned savings are uncertain. Assuming that the economic impacts of all the savings are zero and their effects are sustained, such effects are expected to be at most 5% as annual average. There exists a difference regarding electricity in 2030 between the +21% figure, which can be estimated from the historical evidence, and the +3% figure, which is the baseline assumption of the government. Even if the continuous savings of about 5% after the Fukushima accident are assumed, the economic impacts of the rest of the electricity savings should be investigated carefully. However, the economic analysis requested by the Japanese government does not consider the above economic damages because the baseline assumption of the government is inconsistent with such historical evidence. Therefore, the economic impacts of the “Options for Energy and the Environment” obtained under the official estimation process, with the analyses resulting from the DEARS model that were treated in Section 4, will be underestimated.

Thus, the energy savings under the GDP growth of the baseline scenario assumed by the government are be too optimistic, if the historical trends and the historical savings after the nuclear power accident are considered. Therefore, we modify the baseline scenario of the energy savings, considering the historical evidence of the strong positive relationships between the growth of GDP and power generation and the recent trends of energy savings after the nuclear power accident. The modified baseline scenario of the GDP elasticity for electricity is assumed to be 0.5 for 2010–2030 in this study. Secondly, we revise the baseline on economic growth, in order to be in accord with the GDP growth of 1.0% at least for 2010–2030 found in the Prudent Scenario of the government. The revised baseline has the potential GDP growth of 1.3% per year, as an intermediate assumption between the figures of the Growth Strategy Scenario and the Prudent Scenario of the Cabinet Office of Japan (2012). Therefore, based on these modifications of energy savings and GDP growth, power generation in 2030 in the modified baseline is 1250 TWh.

5.2. **Case studies for the alternative options for energy and the environment strategy**

As mentioned in Section 3, all the options derived by the government assume large increases in renewable energy. The assumptions of drastic increases in renewable energy are estimated to lead to large economic damages. In addition, the assumptions of deep CO_2 emission reductions targets are also estimated to lead to large economic damages. The estimated marginal abatement costs of CO_2 for the options are much higher than those of the international levels reported in several different examples of literature (e.g., EU2011, IEA2011). The differences in cost between Japan and other countries and regions induce carbon leakages that lead to larger economic impacts in Japan and do not necessarily contribute to decreases in the global CO_2 emissions.

In order to provide a wider array of options, and options with reduced GDP damages in particular, this paper proposes alternative options for energy and the environment under the revised baseline as mentioned in Section 5.1. Table 4 shows the major assumptions of the alternative scenarios.

Table 4　Assumptions of the alternative scenarios

	NUC 15%R	NUC 20%R	NUC 25%R	NUC 35%R1	NUC 35%R2
Revised reference case’s GDP	2010-2030: 1.3 p.a. (2010-2020: 1.5 p.a., 2020-2030: 1.0 p.a.)				
Revised reference case’s	2030: about 1250 TWh (GDP elasticity for 2010-2030: 0.5)				

power generation					
Nuclear power share (2030)	15%	20%	25%	35%	
Renewable energy share (2030)	22%	22%	22%	17%	
Energy-related CO_2 emissions (compared to 1990)	Calculated endogenously in the model				
Carbon price	150 \$/tCO_2				100 \$/tCO_2

In the alternative options for case studies in this paper, the shares of renewable energy in 2030 are about 22% in the revised 15%–25% scenarios as shown in Figure 8. The shares in electricity were derived from the results of energy systems model DNE21+ in which the worldwide costs are minimized in the assumed reduction levels (RITE, 2012) under assumed carbon price. However, shares of PV are exogenously assumed, although PV is not estimated to be competitive to other electricity sources according to DNE21+.

The shares of nuclear power are also exogenously assumed, as with the "Options for Energy and the Environment." However, the 35% nuclear power scenario is also assumed as additional information. The 0% scenario is excluded from the alternative options because it is expected that CO_2 emissions will be relatively high under the above assumptions regarding renewable energy, and the GDP growth will be lower than the 1% per year of the Prudent Scenario proposed by the government, even if potential GDP growth is assumed to be 1.3% per year.

In the alternative options, we also assume carbon price. The estimated carbon prices (marginal abatement cost of CO_2) were about 39–55 thousand yen per ton of CO_2 (around \$500 per ton of CO_2) for the "Options for Energy and the Environment" as discussed in Section 4.4. The carbon price was assumed to be about \$150 per ton of CO_2 for the alternative options. The revised carbon prices are lower than the estimated carbon prices of about \$500 per ton of CO_2 for the "Options for Energy and the Environment." However, the level of the alternative carbon price is still higher than that reported by the literature on economic analysis for other countries, as discussed previously. Therefore, a carbon price of \$100 per ton of CO_2 is also assumed for the 35% nuclear power scenario as an additional case study.

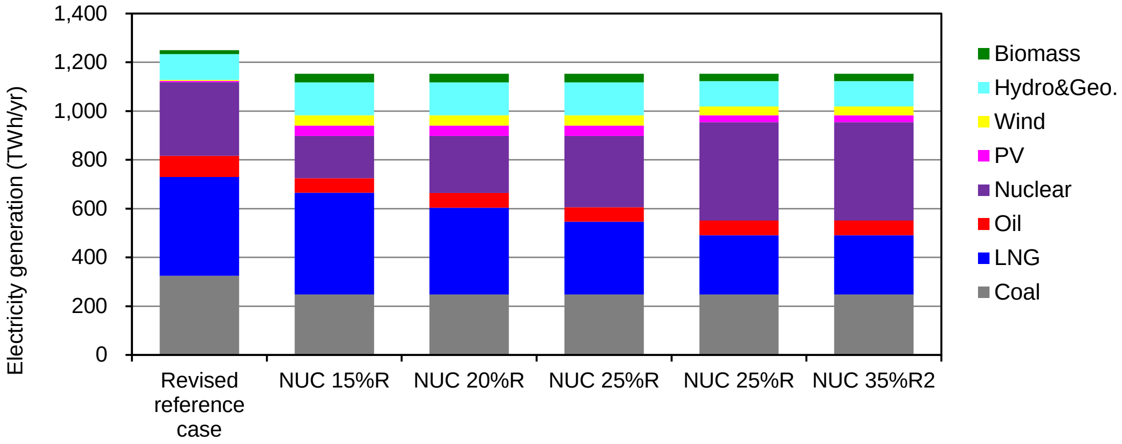

Figure 8 Assumptions of electricity generation in the revised reference case and the alternative options

5.3. Analysis of economic impacts in the alternative options

5.3.1 Impacts on electricity and fuel charges in the alternative options

Figures 9 shows impacts of the alternative options on electricity and fuel charges in 2030. Large improvements in electricity and fuel charges are estimated compared to the revised nuclear power scenario of the options provided by the government due to fewer shares of renewable energy and lower carbon prices. For example, the increases in electricity and fuel charges without and with carbon emission constraints in the revised 15% nuclear power scenario reach +14% and +34% relative to those in the reference case, respectively, although those in the 15% nuclear power scenario of the option assumed by the government reach +22% and +73%, respectively. Further large improvements are estimated in the revised 35% nuclear power scenario and the increases in domestic electricity charges in the revised 35% nuclear power scenario without and with CO_2 emission constraints (carbon prices) are +4% and +20%, respectively. The expected charge increase in the case of $100 per ton of CO_2 in the 35% nuclear power scenario is smaller than that in the case of $150 per ton of CO_2 and +15% relative to the reference case.

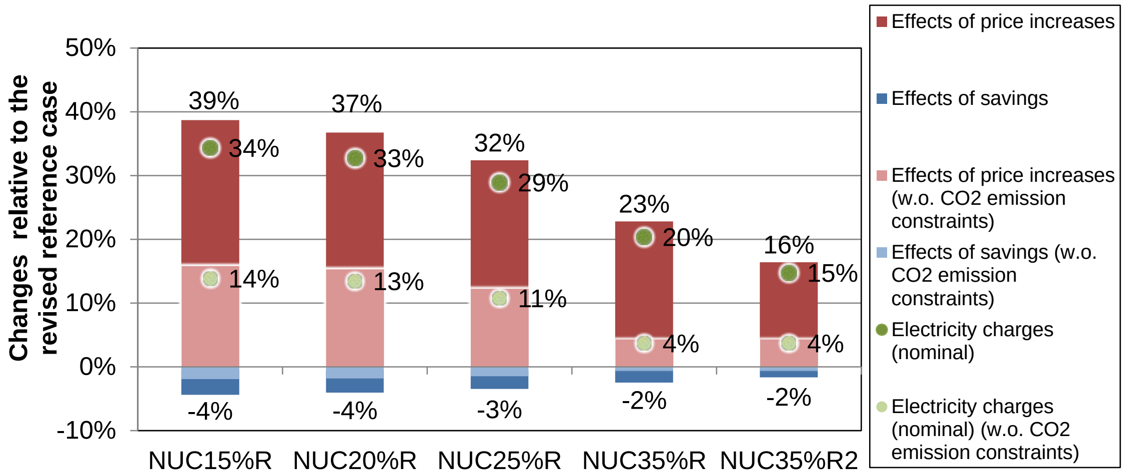

Figure 9 Electricity and fuel charges in the household sector in 2030 in the alternative options, including the effects of price increases and savings

5.3.2 Macroeconomic impacts in the alternative options

Figure 10 shows the impacts on GDP in 2030 in the alternative scenarios under the revised baseline. Considerable improvements in economic impacts are estimated compared to the "Options for Energy and the Environment." This is because the lower renewable shares and modest CO_2 emission reductions are assumed in the revised scenarios. The GDP losses in 2030 in all the revised nuclear power scenarios are within around 2% relative to the revised baseline. The GDP growth in all the revised nuclear scenarios are beyond the GDP growth rate of 1.0% per year assumed in the Prudent Scenario proposed by the government. At the same carbon price in the revised scenarios, the GDP losses are dependent on shares of nuclear power. Hence, the GDP loss in the case of the 35% nuclear power scenario is much smaller than that in other cases and 1.6%, although increases in nuclear power shares are not expected, due to the negative attitudes toward nuclear power among a large part of general public after the severe accident. If a carbon price of $100 per ton of CO_2 is assumed in the case of the 35% nuclear power scenario, the economic impacts will be further diminished, where the expected GDP loss is 1.1%.

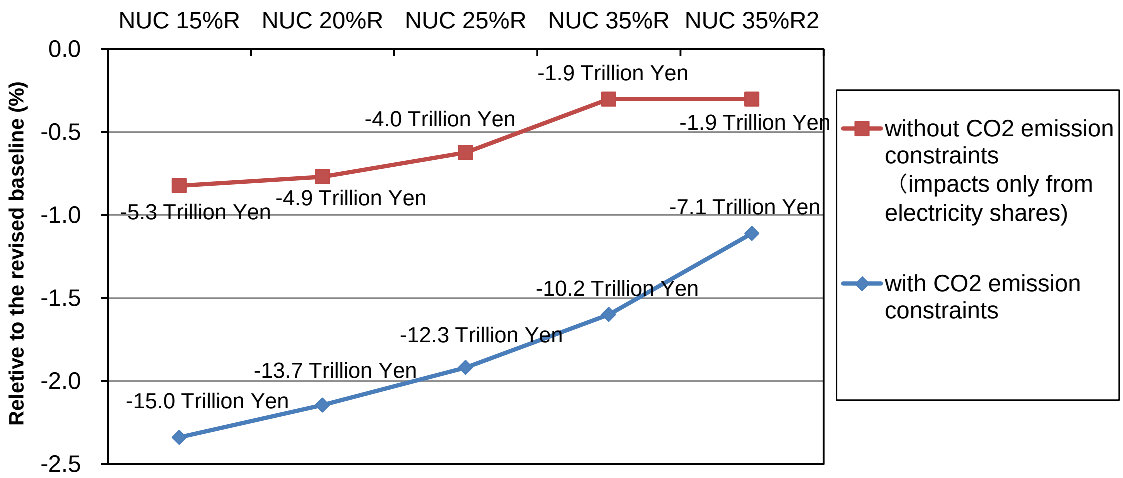

Figure 10　GDP losses in 2030 in the alternative scenarios

5.3.3 CO_2 emissions in the alternative options

CO_2 emission reductions in the alternative options are smaller than those of the options assumed by the government while carbon price assumed in the revised scenario is higher than that reported for the international levels, as mentioned in Section 5.2. The CO_2 emission reductions estimated in the revised 15%, 20%, 25%, and 35% nuclear scenarios in which carbon price is assumed at $150 per ton of CO_2 are around 8%, 10%, 12%, and 15% relative to 1990, respectively. The estimated reduction in the case of $100 per ton of CO_2 in the revised 35% nuclear power scenario is around 14%. These reductions are smaller than those assumed in the options proposed by the government, as shown in Table 3. There will be other possible ways in which to resolve the differences in CO_2 emission reductions between the alternative options and the options proposed by the government, including contributions to international emission reductions such as the bilateral offset credit mechanism for achieving emission reductions abroad through diffusion of energy saving technologies and commodities.

6. Conclusion

This paper provided economic analyses of the “Options for Energy and the Environment” proposed by the Japanese government, using the DEARS world energy-economic model. The options were proposed by the previous governmnet after the severe accident of Fukushima Daiichi nuclear power plant resulting from the Great East Japan Earthquake and Tsunami.

The simulation result reveals that the “Options for Energy and the Environment” and the “Innovative Strategy for Energy and the Environment” of the government assume drastic energy efficiency improvements and increases in renewable energy at levels that are difficult to achieve economically. While a strong positive relationship between GDP growth and electricity demand increase has been observed, the relationship in the scenarios of the government regarding are assumed to be disappeared even in the baseline. Large savings of electricity have been achieved since March 11, 2011, in Japan. However, the differences between the assumed electricity savings even in the baseline for the options and the strategy by the government are still large.

Firstly, this paper modified the baseline scenario for a greater consistency with historical trends. Secondly, this paper proposes alternative options for energy and environment strategy under the revised baseline assumptions and analyzes the economic impacts of such options. The economic impacts of the alternative options are much milder than those of the scenarios proposed by the government. The new cabinet established in December 2012 has a plan to rebuild a new strategy. Our analyses of the economic impacts in this paper will help stimulate expected future discussions for rebuilding a new energy and environment strategy in Japan.

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