Impacts of Post-Fukushima Nuclear Policies on Roadmaps towards a Low-Carbon Society in Japan

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1. Introduction

On March 11, 2011, Japan suffered a big earthquake and tsunami (the so-called Great East Japan Earthquake). Nuclear power plants in the northern part of the main island of Japan were shutdown (15 units). On the day of the disaster 55 nuclear power units were in commercial operation (including 18 units under periodical inspection) and 12 units were under construction. On May 6, 2011, the then Prime Minister, Naoto Kan, made a request to the Chubu Electric Power Company (CEPCo) to shutdown Hamaoka Nuclear Power Plant No.4 and No.5 on the grounds of an insufficient security system for coping with a tsunami. On May 9, CEPCo accepted the request and 2 of the Hamaoka Nuclear Power plants were shutdown. After the earthquake, some nuclear power plants had periodical inspections, however, no nuclear power plants allow restarting, rendering around 85% of the units off-line on December 20, 2011 as shown in Figure 1.

Total installed capacity is 49,378 MW and capacity under construction is 17,908 MW. Okinawa EPCo has no nuclear power and no future plans to construct nuclear power stations. After the earthquake, Tohoku EPCo shutdown all the nuclear power plants it owned (Onagawa: 2,174 MW and Higashi-dori: 1,100 MW). TEPCO also shutdown their nuclear power plants on the Pacific coast due to the earthquake, (Fukushima Daiichi: 4,696 MW and Fukushima Daini: 4,400 MW). Kashiwazaki-Kariwa Nuclear Power Plant is on the Sea of Japan coast and was not affected directly by the earthquake, so except for a few units under periodical inspection, some nuclear power capacity remained in operation. As a result, in the summer 2011 areas in which the Tohoku EPCo and the TEPCO operate faced a deficit of electricity supply due to lack of electricity supply from nuclear power. The Ministry of Economy, Trade and

Industry (METI) invoked an electricity usage restriction order demanding a 15% reduction in electricity consumption to customers who have contracts of 500kW or more as a maximum limit for electricity usage in the Tokyo and Tohoku regions, based on the Electricity Business Act.

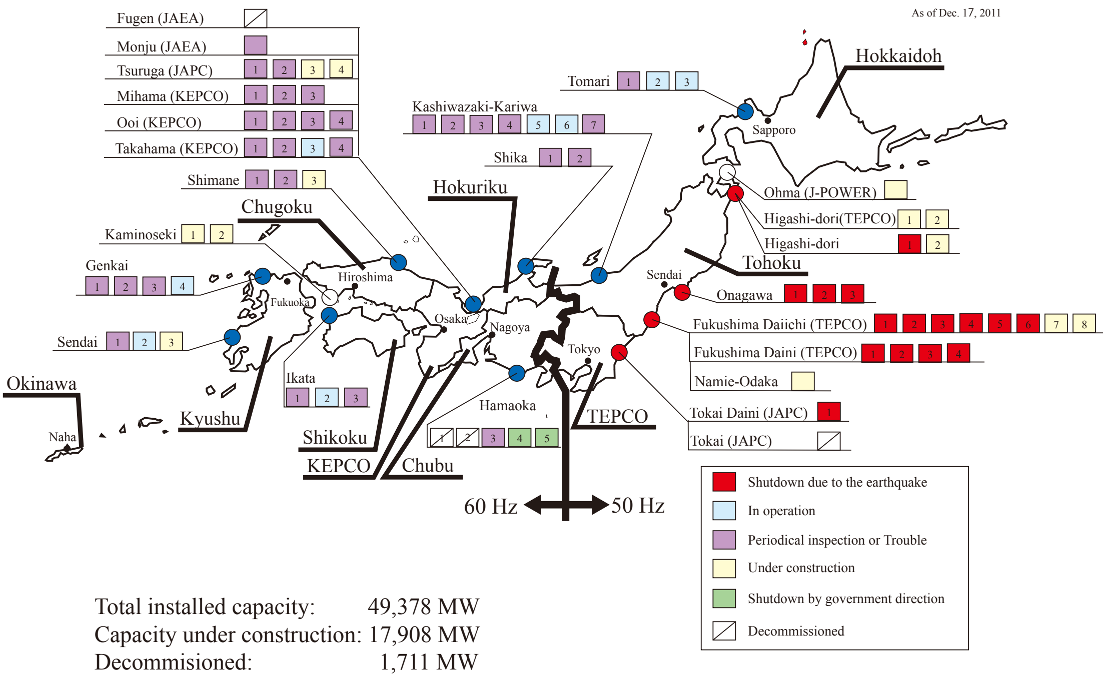


Figure 1: Current status of nuclear power in Japan (As of December 20, 2011)

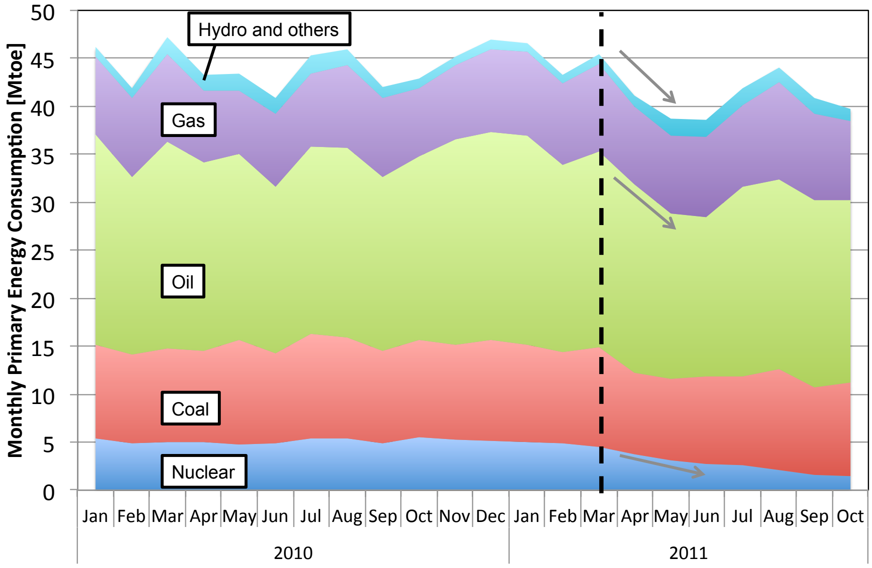


Figure 2. Primary energy consumption from January 2010 to October 2011.

Figure 2 shows monthly primary energy consumption by fuel from January 2010 to October 2011. Compared to the energy consumption trend in 2010, total energy consumption in 2011 decreased drastically, especially in April and May. One reason of decrease in energy consumption is climate condition in spring season. For example, in Tokyo, average maximum temperatures in April and May are 18.8^{o}C and 22.8^{o}C and average minimum temperatures are 10.7^{o}C and 15.4^{o}C [1], resulting in the reduction of warming service demand during the months. Because cooling service demand increases, primary energy consumption in July and August grows up even under the electricity usage restriction.

The nuclear accident in the Fukushima awoke public concern about nuclear energy policy as well as overall energy policy in Japan. Before the earthquake, the priority of Japan's energy policy was ensuring a stable supply of energy, and key policy actions are diversification of energy supply and energy saving. Nuclear power was one of leading players of diversification of energy sources. In contrast it now seems that ensuring the safety of the supply of energy has become the priority of energy policy. Key policy actions in the future are on the table and representatives and experts have made proposals for ensuring safe energy by, for example, denuclearization and/or the phase-out of nuclear power, enhancing renewable energies and spreading fossil-fueled power plants [2-6]. It is still unclear how these will affect energy policy options for the long-term energy situation, especially pathways towards a low-carbon society in Japan.

The question we have to ask now is: does Japan continue to center conventional energy sources such as fossil fuel and nuclear as our energy policy, or take step toward new energy era? Or, more concretely, if Japan shifts from nuclear power to other fuels, such as renewables; is it possible to keep stable supply of energy? Pledge of GHG emissions will be fulfilled? And how the necessity of electricity saving?

The purpose of this study is to re-depict future pathways for Low Carbon society in Japan in consideration of changes in Japan's nuclear energy policy by using simulation model.

2. Methodology for the analysis

The AIM/Backcasting Model [7, 8] in this study is used to investigate and select which options (countermeasures and policies) to introduce, and when and at what intensity, in order to best achieve the future social and economic activities portrayed in the scenarios while satisfying the service demand today and throughout the period up to the target year, based on certain criteria. Industrial structures in the base and target years are set as exogenously, and the values for the other years (intermediate years) are estimated endogenously by the model. Energy consumption and the composition of CO_2 emissions in the base year are set based on statistics [9-11], and future values are determined endogenously. Mixed integer programming is used for formulation and the Cplex solver with the General Algebraic Modeling System (GAMS) is used for derivation of the optimal solution. Figure 3 shows assessment schemes in the AIM/Backcasting Model.

The base and target years in the current study are set as 2000 and 2050, respectively. Pathways for achieving the target with a 80% reduction of CO_2 emission (compared to the 1990 level) are investigated by estimating the investment in CO_2 reduction options and energy balance every 5 years so as to minimize the total cost throughout the entire analysis period (calculated in present value) while maintaining the activities of the scenarios under the CO_2 emission restrictions in 2050.

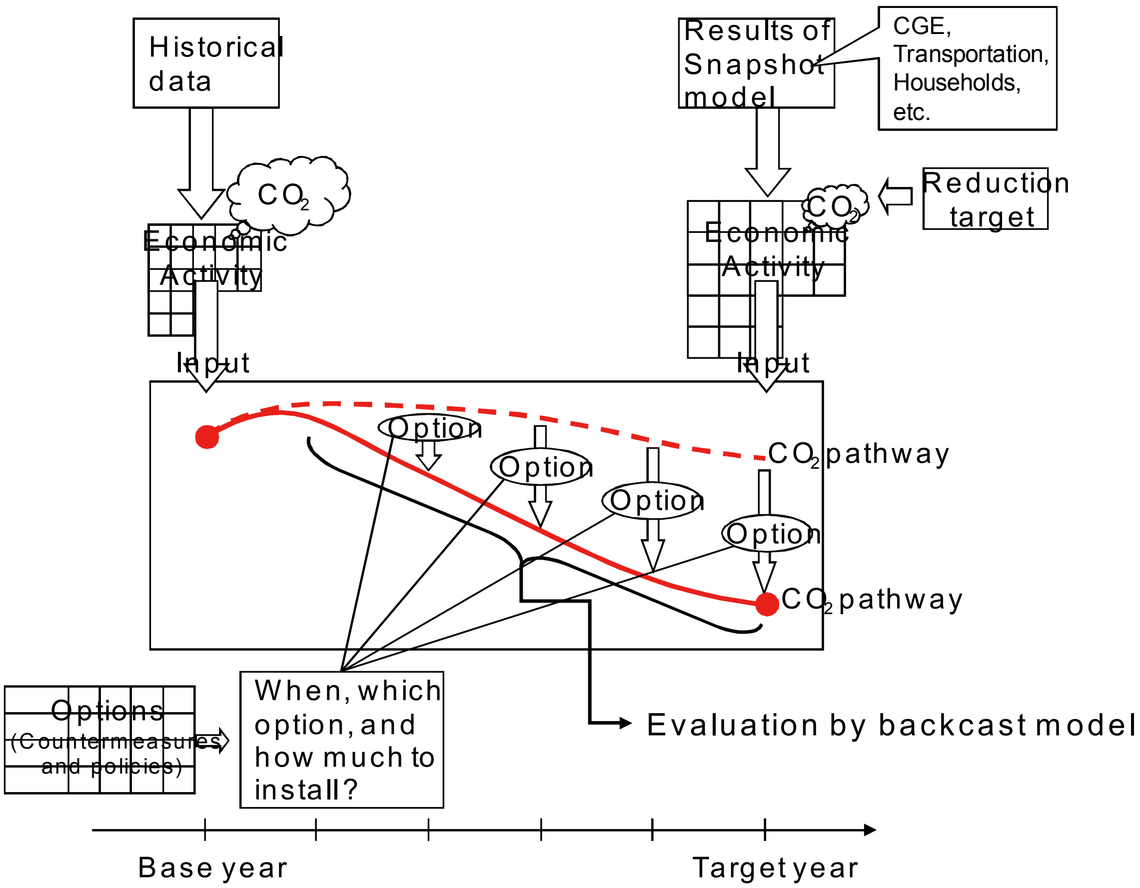


Figure 3: Schemes of the flow of estimation using a backcast model

3. Assumptions for the analysis

3.1. Nuclear policy options in the future

Future energy policy will respond to the availability of nuclear power, so two sets of cases have been made as future energy policy options. All cases are based on the premise that the Fukushima Daiichi Nuclear power plants never restart.

The first case set is for existing nuclear power plants. The case has five options: (1) no restart (all nuclear power shutdown now and never restarted, NO), (2) partial restart with a life of 40 years (restarting will allow for nuclear power with the exception of plants damaged by the earthquake, and continue to commercial operation for 40 years, Part40), (3) partial restart with a life of 60 years (restarting will allow for nuclear power with the exception of plants damaged by the earthquake, and continue to commercial operation for their lifetime. The lifetime of power plants extends from 40 years to 60 years, Part60), (4) full restart with a life of 40 years (all nuclear power plants are allowed to restart and continue commercial operation for 40 years, Full40), and (5) full restart with a life of 60 years (all nuclear power plants are allowed to restart and continue commercial operation for their lifetime. The lifetime of power plants extends from 40 years to 60 years, Full60).

The second case set is for new nuclear power plants. The case has three options: (1) withdrawal (all nuclear power both under construction and under planning is withdrawn, WD), (2) construction only (only nuclear power plants currently under construction will be allowed to start commercial operation, and plants under planning are withdrawn, CON), and (3) enhancement (future nuclear policy continues to follow the policy that was conducted before the earthquake, EH).

The analysis was conducted based on a combination of two case sets as shown in Table 1. Under the no restart case, the new construction of nuclear power is quite unlikely to be permitted, so in the analysis two cases (No-CON and No-EH) have been eliminated. The partial restart case assumes that the nuclear power status quo will be maintained and the Part40-EH and Part60-EH scenario was dropped from the case set. Figure 4 shows the capacity of nuclear power by case. The No-WD (No restart for existing plants and Withdrawal for new nuclear power) case corresponds to denuclearization, and combination of Full restart with a life of 60 years case and Enhancing case (Full60-EH) is almost same as nuclear energy policy before the earthquake except for missing Fukushima Daiichi Nuclear Power plants. Other cases are almost comparable to the phase-out.

Table 1. Case sets analyzed

		Options for new nuclear plants		
		Withdrawal	Construction only	Enhancement
Options for existing nuclear power plants	No restart	No-WD	-	-
	Partial restart with a life of 40 years	Part40-WD	Part40-CON	-
	Partial restart with a life of 60 years	Part60-WD	Part60-CON	-
	Full restart with a life of 40 years	Full40-WD	Full40-CON	Full40-EH
	Full restart with a life of 60 years	Full60-WD	Full60-CON	Full60-EH

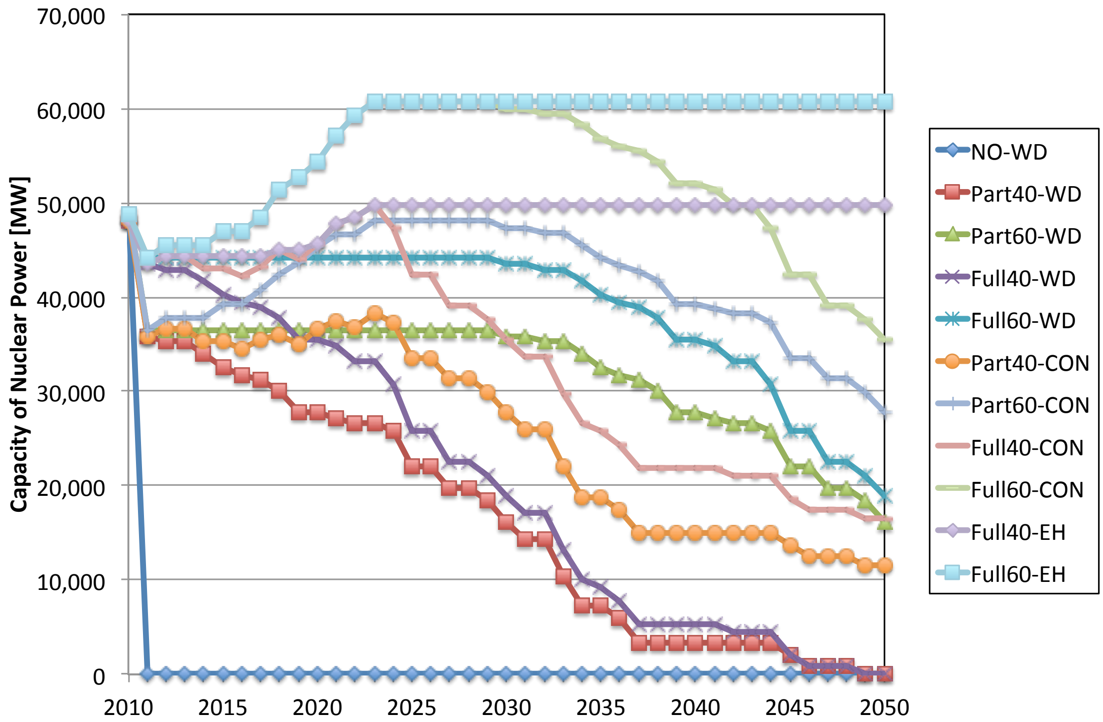


Figure 4. Capacity of nuclear power by case

3.2. Assumptions for the analysis

It is difficult to predict accurately what direction the society and economy in Japan will take in the years leading up to 2050. For this reason, it was decided to establish two different future visions and study the roadmap to an 80% reduction for both visions, and to then depict the achievability of an 80% reduction in CO_2 emissions in Japan by 2050 and the roadmap to this goal based on Fujino et al. [12].

In this study, by reference with the Ashina et al. [7, 8], two scenarios were established: a technology-oriented economic development scenario (Scenario A) and a nature-oriented, regionally-centered scenario (Scenario B) to study the roadmap to an 80% reduction. Table 2 presents an overview of the vision of society for each of the proposed scenarios. For the purposes of this analysis, only the CO_2 reduction technologies that are presently expected to be achieved have been considered. Specifically, approximately 470 types of technology in all sectors were assumed: high-efficiency air conditioners and LED lights and so on in the home sector, high-performance boilers and fuel conversion in the industrial sector, hybrid automobiles and electric vehicles in the transport sector, and high-efficiency thermal power generation and combined CCS and thermal power generation and so on in the energy supply sector.

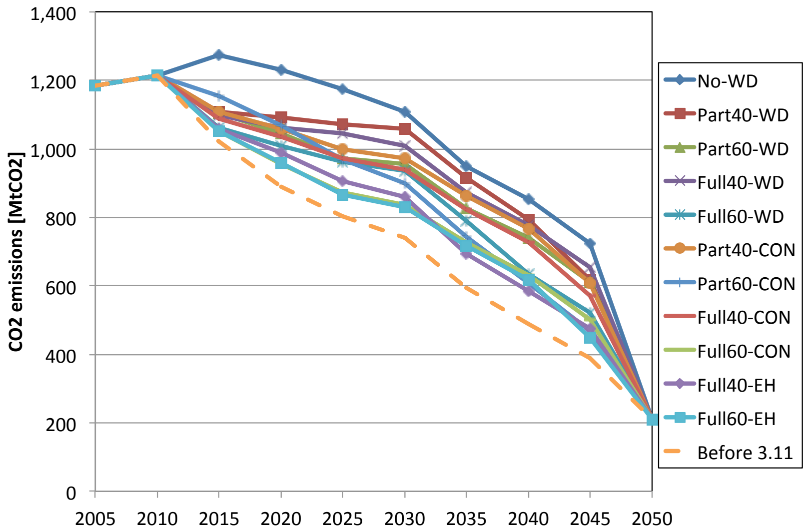
Table 2. Overview of the future vision of society in 2050[7, 8]

	Overview
Scenario A	• Population and capital is centered in the city center in pursuit of convenience and efficiency • High proportion of apartment residence and low number of residents per household • GDP growth rate of 1.0% per year is achieved (per capita 1.7% per year) • Society becomes a center for the creation of high-quality goods
Scenario B	• Population and capital is dispersed to regional areas in pursuit of quality of life • Slight increase in the proportion of apartment residents but trend toward living together with family • GDP growth rate of 1.0% per year is achieved (per capita 1.7% per year) • Mature society that represents a departure from material affluence is formed

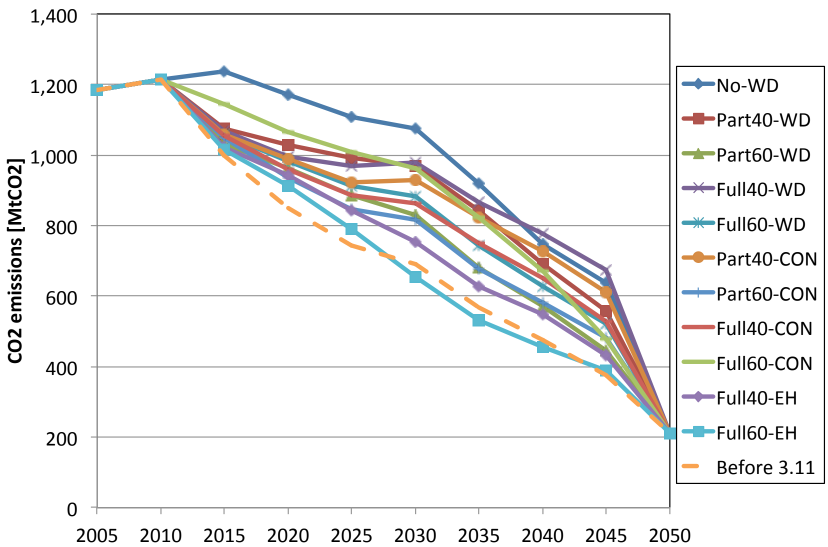
4. Results and discussions

Figure 5 shows CO_2 emission pathways from 2005 to 2050 both for the scenario A and B. “Before 3.11” indicates results of Ashina et al. [7] which analyzed future CO_2 emission pathways based on the condition before the earthquake.

Japan has been set an 80% reduction of GHGs by 2050 as a long-term climate change mitigation target. 95% of Japan's GHG emissions come from CO_2 emissions from energy use, and the mitigation target interprets an 80% reduction of CO_2 emissions by 2050. We can see from the figure that, even in the No-WD case (denuclearization), an 80% reduction target in 2050 is feasible. However, required reduction of CO_2 emissions from 2045 to 2050 is 510 $MtCO_2$, which corresponds to half of CO_2 emissions in 1990. Compared to the scenario A, CO_2 emission pathways in the scenario B relatively close to the optimal CO_2 pathways analyzed before the earthquake, because future service demand relatively lower than that of scenario A.



(a) Scenario A



(b) Scenario B

Figure 5. CO_2 emission pathways under analyzed cases

Prior to COP15, the then Prime Minister, Yukio Hatoyama, pledged a 25% emission reduction target by 2020, promised upon the establishment of a fair and effective international framework during a speech at the UN Summit on Climate Change in September 2009. Although the commitment did not show an allowance for domestic reduction, the No-WD case seems not to satisfy the commitment.

Figure 6 shows primary energy composition in 2050 by case. It is clearly shows that, as an energy supply from nuclear power reduces, total primary energy consumption is decreased and nuclear and coal energy shift to gas energy. Renewables such as solar and wind does not grow so much because almost of all technological potential is adopted in the results which conducted before the earthquake. The results in the scenario B show similar trends.

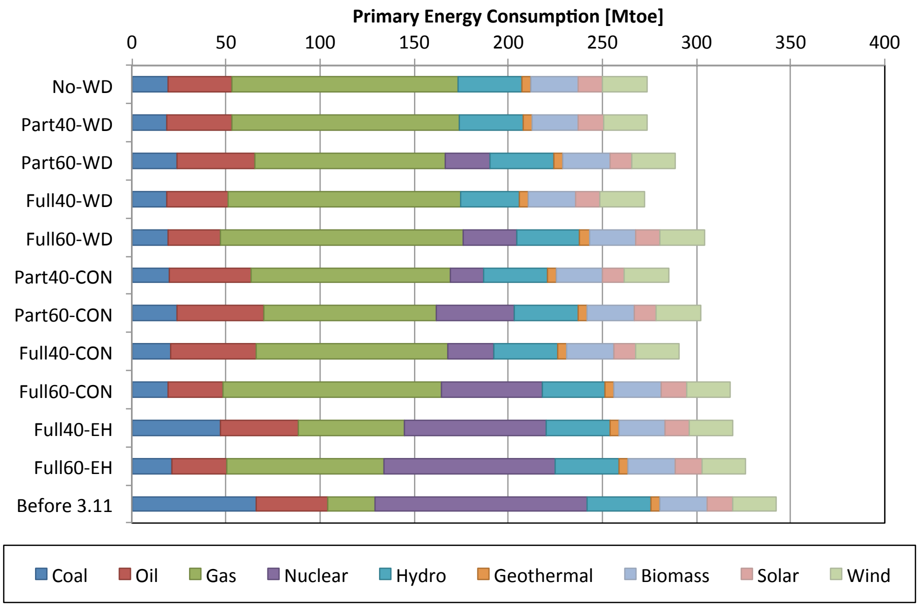


Figure 6. Energy composition in 2050 by case (Scenario A)

For a roadmap determined from the standpoint of the total cost minimization needed to achieve an 80% reduction in CO_2 emissions by 2050, if one focuses on the trends in yearly additional investment as compared to the "technology frozen" case, additional investment of 4 - 6 trillion JPY will be needed in 2010 among cases (Fig. 7). This investment amount does not include the cost of super-insulated residences and structures and the cost needed to change city infrastructures to create more compact cities. By sector, the additional investment for the household sector is the largest, followed by the business sector, the transport sector and the industrial sector. Beginning in 2015, annual additional equipment costs will amount to 2 - 3 trillion JPY, but because it will be possible to reduce fuel costs by JPY 2 - 3 trillion due to reduced energy consumption, the total additional cost will be a zero. In 2045, additional costs of 2-6 trillion JPY for cases which maintains certain capacity of nuclear power in 2050 and approximately 13 trillion JPY for cases without nuclear power in 2050 will be needed due to the introduction of countermeasure technologies among all sectors, that are effective in reducing both energy consumption in the enduse sector and CO_2 emissions but are expensive. The learning effect relating to investment costs for countermeasure technologies is not included in this study. However, if a gradual reduction in investment costs for countermeasure technologies can be anticipated due to a learning effect, it is possible that the case in which all nuclear power will be expired by 2050 may be less expensive than the "technology frozen" case in terms of energy systems as a whole.

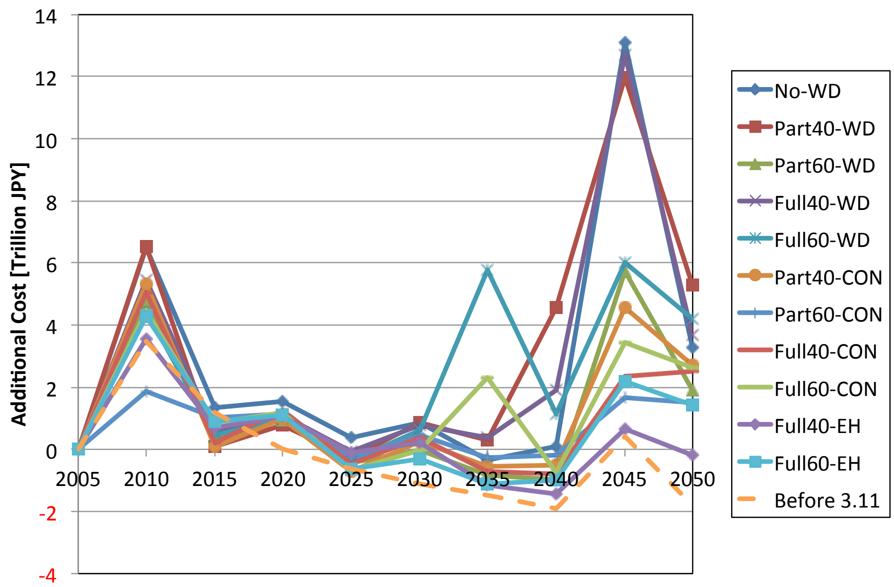


Figure 7. Additional investment by the scenario (Scenario A)

5. Conclusion

Even now halted all existing/constructing nuclear power plants and plans, 80% reduction of CO_2 emissions by 2050 are tough but feasible. A roadmap for 80% reduction without nuclear requires three essential options: energy conservation in the enduse sectors, large scale deployment of carbon capture and storage (CCS) and energy shift from both nuclear and coal to gas. It is also found from the results that, if no additional policies and countermeasures will be adopted by 2020, Japan will not meet 25% reduction target of greenhouse gas emissions by 2020. Length of life of nuclear power mainly affects CO_2 emissions from 2020 to 2030 (mid-term), rather than whether to restart a nuclear power which suffered the earthquake. In order to realize 80% reduction by 2050 without nuclear power, large additional investments would be required from 2040 to 2050, however, when considering the learning effect for the low carbon technologies, additional cost may reduce and a low carbon society could realize more cost-effectively.

Discussion of energy policy after the earthquake is likely to commence soon, and denuclearization is an option for the energy policy portfolio in Japan. Based on the analysis, we found that from a long-term viewpoint, Japan can satisfy both denuclearization and low-carbonization. However, without an intelligent strategy for low-carbonization, CO_2 will continue to grow and the climate change mitigation target of 80% reductions in GHG emission by 2050 will be left unfulfilled, because nuclear will be substituted by coal, which is a large fossil fuel emitter of CO_2.

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