Long Term Energy System Analysis of Japan after March 11, 2011

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Abstract

The Great East Japan Earthquake in 2011 has made significant impacts on the Japanese economy as well as energy systems. After this historical disaster, it is quite important to reconsider Japanese energy system design from long-term perspectives. Implications to Japanese energy system are discussed especially in terms of primary energy supply and power generation portfolio, using sensitivity analysis results by an optimization type energy model based on TIMES modeling framework. We referred MARKAL-JAPAN framework for energy supply and conversion structure, and updated energy service demand. The time horizon of the model is 2050. We assume that nuclear and climate change are the major policy constraints of the energy system in Japan. The sensitivity analysis results are presented for cases such as nuclear phase out with and without CO_2 constraints. Roles of various energy supply options are presented including nuclear, fossil fuel and renewable in Japanese energy system.

Keywords: Energy model, TIMES, CO_2 emissions;

1. Introduction

The Great East Japan Earthquake on March 11, 2011 has made significant impacts on the Japanese economy as well as energy systems in long term. The power system suffered severe damage, in particular, the earthquake and tsunami hit Fukushima Daiichi nuclear power plants and some reactors experienced severe accidents. In addition, most of the other nuclear power plants are not in operation. The effects of the earthquake to electric power supply and demand will continue several decades, because nuclear issues are recognized as social problem. It is obvious that Japanese energy system is in a turning point. Therefore, the Japanese government is planning to redesign its energy policy including nuclear.

For this purpose, it is necessary to reconsider energy balance in the long term point of view. Komiyama et al.[1)] and Matsuhashi[2)] reported their analytical results of the long term energy balance of Japan considering the influence of the earthquake. In addition, more studies are required for detailed discussion on the energy policy of Japan in future.

The authors have made a new single region optimization energy system model based on TIMES modeling framework. Using this model, the energy balance of Japan was analyzed to 2050. Analyzed scenarios were including nuclear phase out with and without CO_2 constraints for this analysis.

2. Simulation method and scenario assumption

2.1. Energy model framework

The authors referred MARKAL-JAPAN

framework[3)4)] for reference energy system. MAKAL-JAPAN framework is an energy model for Japan developed by former Japan Atomic Energy Research Institute (JAERI), presently Japan Atomic Energy Agency (JAEA).

We updated energy service demand estimate and primary energy supply price in future by up-to-date information and then built a linear energy model for Japan with TIMES modeling framework developed by the Energy Technology Systems Analysis Program (ETSAP) of International Energy Agency (IAE). It should be noted that one of the authors has assessed global energy system under nuclear and/or CO_2 constraints with different modeling framework[5)6)].

The model has the following features;

* Time periods : Starting from 1990 to 2050, with five-year time step.
* Objective function : Total discounted energy system cost.
* Discount rate: 3 %
* Electric load curve: One year is divided into three seasons (i.e. winter, summer, spring and autumn) and each season is also divided into two (i.e. day and night). The annual peak electricity demand is considered.

2.2. Prerequisite for analysis

We employed the assumptions including;

* Annual GDP growth rate:1.2 %/yr from 2000 to 2010, 0.6 %/yr from 2010 to 2030, and 0.0 %/yr from 2030 to 2050.
* Crude oil import price: In this paper, all currency term are expressed in real 2010 US dollars. Future price was estimated based on the assumption in "New Policy scenario" by IEA[7)] to 2035 and this assumption is linearly extended to 2050 as shown in Fig. 1(a) (79.2 $/bbl in 2010, 115.4 $/bbl in 2050).
* Steam coal import price: Future price increases at 1.1 %/yr as shown in Fig. 1 (b) (90 $/t in 2010, 130 $/t in 2050).
* Liquefied natural gas (LNG) import price: Future price was estimated based on the assumption by "Gas scenario" by IEA[8)] to 2035 and this tendency is linearly extended to 2050 as shown in Fig. 1(c) (9.4 $/Mbtu in 2010, 14.4 $/Mbtu in 2050).
* Uranium import price: Future price increases at 0.67 %/yr (61 $/lb U_3O_8 in 2010, 77 $/lb U_3O_8 in 2050).
* Upper bound of photovoltaics (PV) power capacity : 40 GW in 2030, 70 GW in 2050.

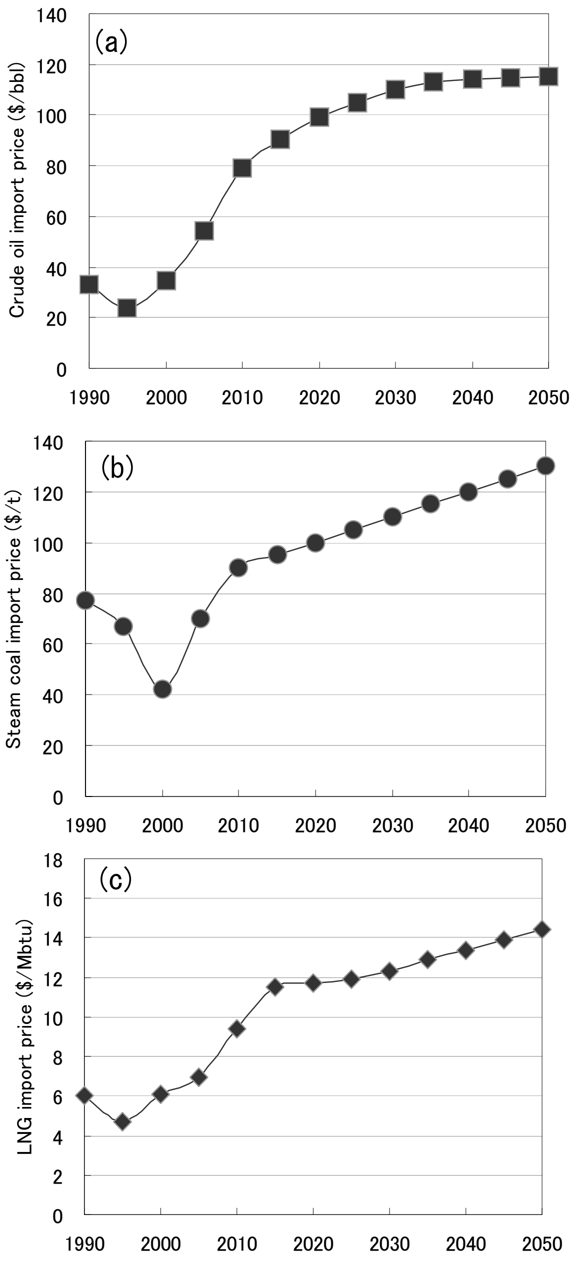

Fig. 1 Fossil fuel import price:
(a) crude oil, (b) steam coal, (c) LNG

2.3. Energy service demand

In this modeling framework, the final energy demand sectors are industry, commercial, residential and transportation. Energy service demand was estimated for each sector with sub-sectors.

In the industry sector, we defined "resource intensive industries" as iron and steel industry, cement industry, paper and pulp industry. As shown in Fig.2 (a), production decreased from 2005 to 2010 in these industries. In addition, it is assumed that the production will recover by 2020 and then will decrease again after 2030. For other industries, energy service demand is assumed to increase by 2020 and then decrease after 2030 as shown in Fig. 2 (b). In this figure, "Power", "Boiler" and "Heating" represent those for other industries excluding glass and chemicals production.

Figure 3 shows the energy service demand for the commercial and residential sectors. For the commercial sector, it is assumed that energy service demand will increase continuously and have a peak in 2030. For the residential sector, the energy service demand will show a plateau by 2030, and then gradually decrease to 2050 due to the decline of population and the number of households in Japan.

For the transportation sector, transportation services are assumed for passengers (passenger -kilometer) and freights (ton-kilometer) as shown in Fig.4. In this figure, "Int. Air" and "Int. Ship" represent international aviation transportation and international shipping, respectively. For motor transportation including passenger vehicles, buses and trucks, our assumption is based on "New estimation for transportation demand in future" by the Ministry of Land, Infrastructure, Transport and Tourism[9]. It is assumed that the service demand for passenger vehicles and ship cargos for international transportation will decrease after 2030.

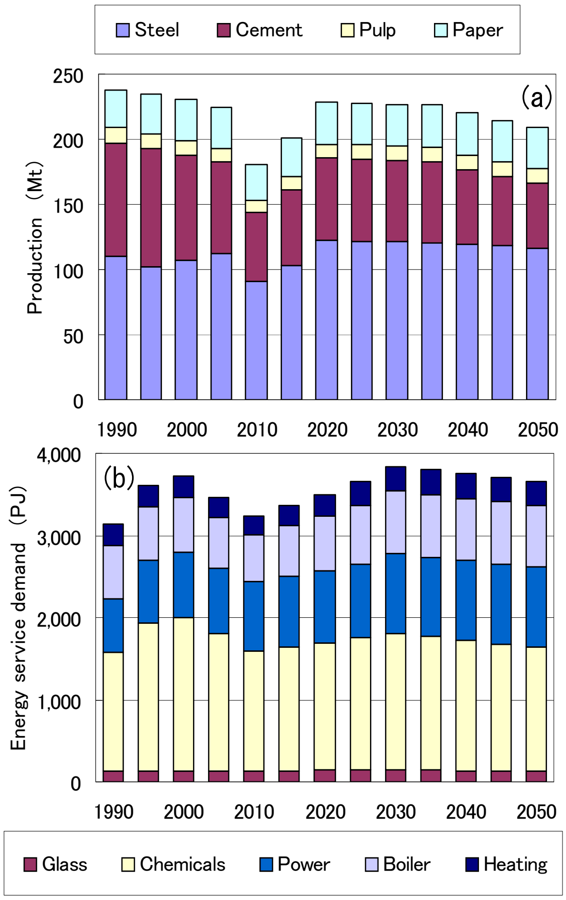

Fig.2 Energy service demand in (a) resource intensive industries and (b) other industries

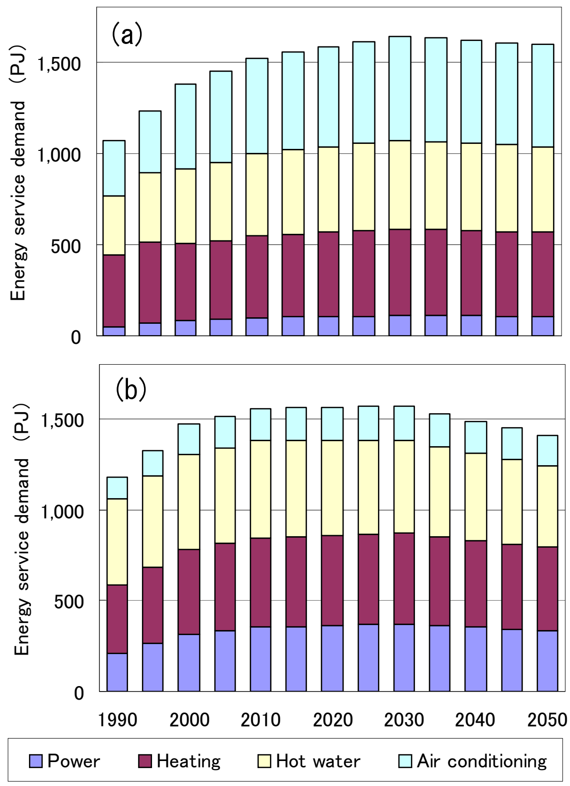

Fig.3 Energy service demand in (a) commercial and (b) residential sectors

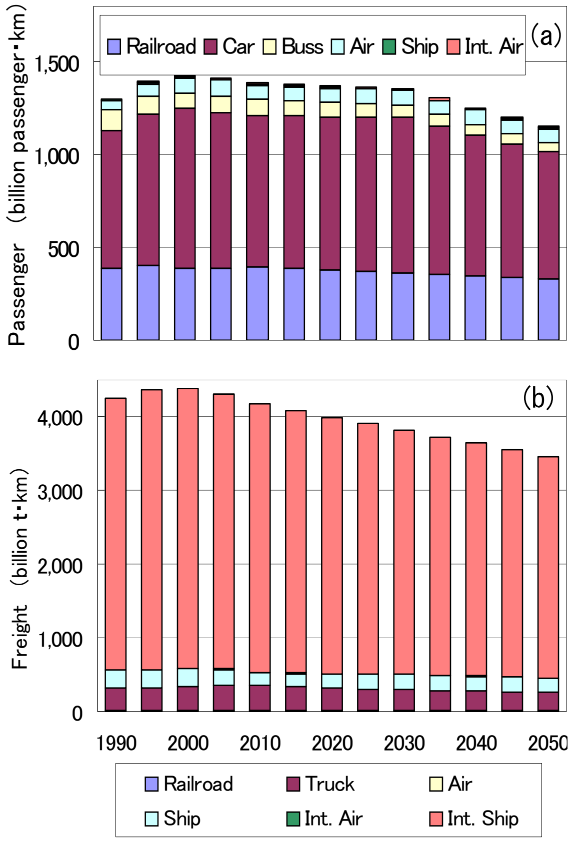

Fig.4 Energy service demand in the transportation sector:
(a) passengers and (b) freights
(Int. Air: International aviation,
Int. Ship: International shipping)

2.4. Scenario assumption

The authors assumed that nuclear power generation and global warming are the major policy constraints for the energy system in Japan by the middle of the century. In particular, nuclear is presently in very difficult situations; the nuclear position as power supply has been drastically changed by the direct damages due to the earthquake and tsunami, safety check request and social acceptance. Therefore, it is difficult to expect large expansion of nuclear power plants installations.

Climate policies aiming at drastic CO_2 reduction announced before March 11 includes large expansion of nuclear capacity. It is obvious that energy system portfolio with CO_2 mitigation should be revised reflecting the current situation. This situation is taken into account for the analysis.

In this study, “Base case” scenario means energy balance planned before the earthquake. This corresponds to the latest energy policy of Japan shown in “Continuous effort scenario” of “Long term energy supply and demand perspectives” by the Ministry of Economy, Trade and Industry[10].

Nuclear phase out is assumed in “Nuout case”, that is, Fukushima Daiichi and Daini power plants will be decommissioned, other existing power plants will be stopped after 40 years operation, and no new nuclear power plant will be installed. In addition to the nuclear phase out, constraint is assumed for CO_2 emissions in “NuoutTax case” by introducing high carbon tax after 2015.

3. Results and Discussion

3.1. Primary energy supply

In all cases, the primary energy supply remains almost steady at the present level before 2030, and then gradually decreases to 2050 as shown in Fig. 5. In particular, oil supply decreases remarkably. For the nuclear phase out without CO_2 constraint (Nuout case), the nuclear power generation is mainly replaced with coal. On the contrary, the nuclear and a part of coal are replaced by natural gas in NuoutTax case with the CO_2 constraint.

3.2. Final energy consumption

Figure 6 shows the final energy consumption for each demand sector in Base case. The total final energy consumption has a peak in 2030 and then decreases continuously to 2050. In particular, the final energy consumption in the transportation sector decreases remarkably. The final energy consumption also decreases in the commercial and residential sectors. On the contrary, the final energy consumption in the industry sector is almost steady from 2030 to 2050. These results are also observed in Nuout and NuoutTax cases.

Figure 7 shows the final energy consumption for each energy supplier. In all the cases, electricity and city gas consumption (except for gas fired power generation) increases by 2030 and then reach a plateau to 2050. On the other hand, oil consumption decreases steeply to 2050. In Fig.7, “others” represent solar thermal, hydrogen and so on. These consumptions are increasing, in particular, in NuoutTax case due to the CO_2 constraint.

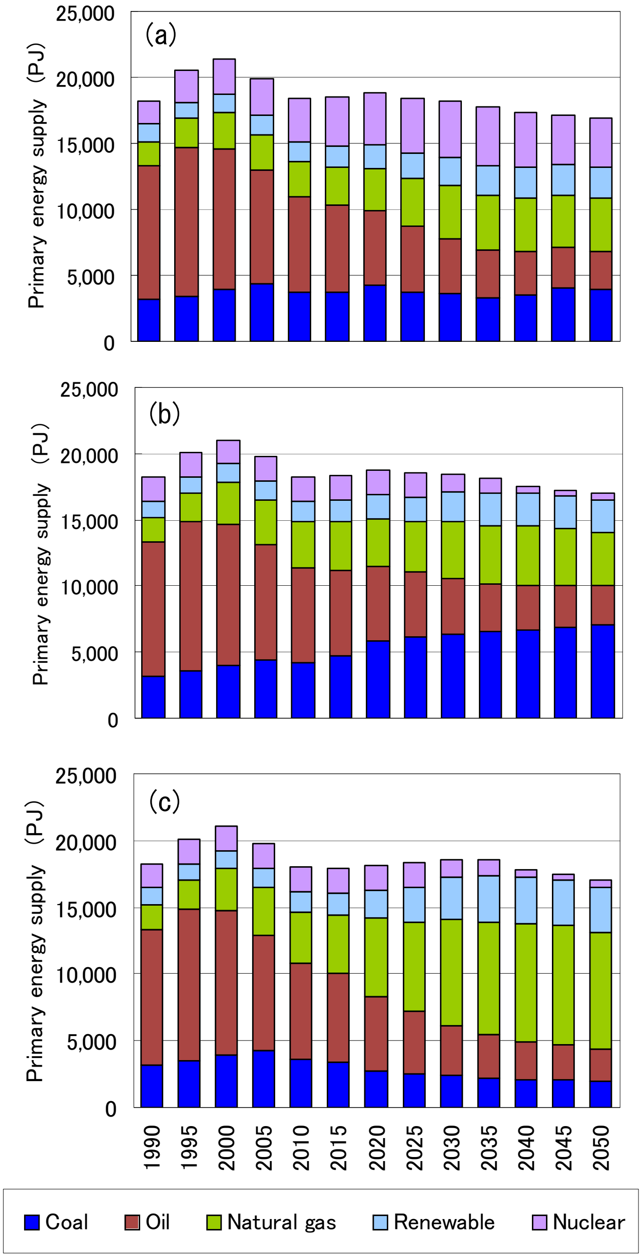

Fig.5 Primary energy supply in (a) Base case, (b) Nuout case and (c) NuoutTax case

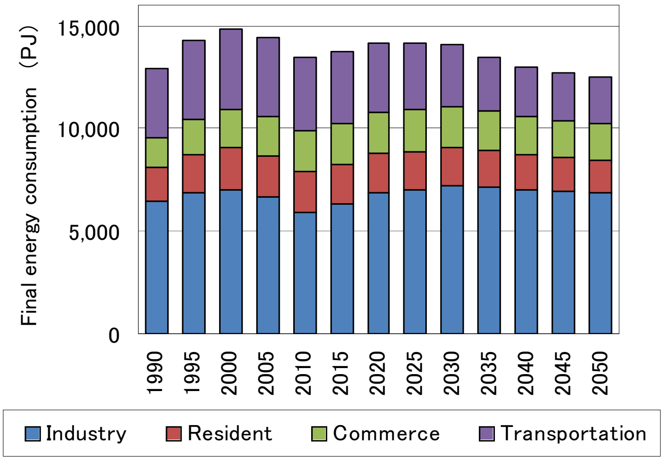

Fig.6 Final energy consumption in Base case

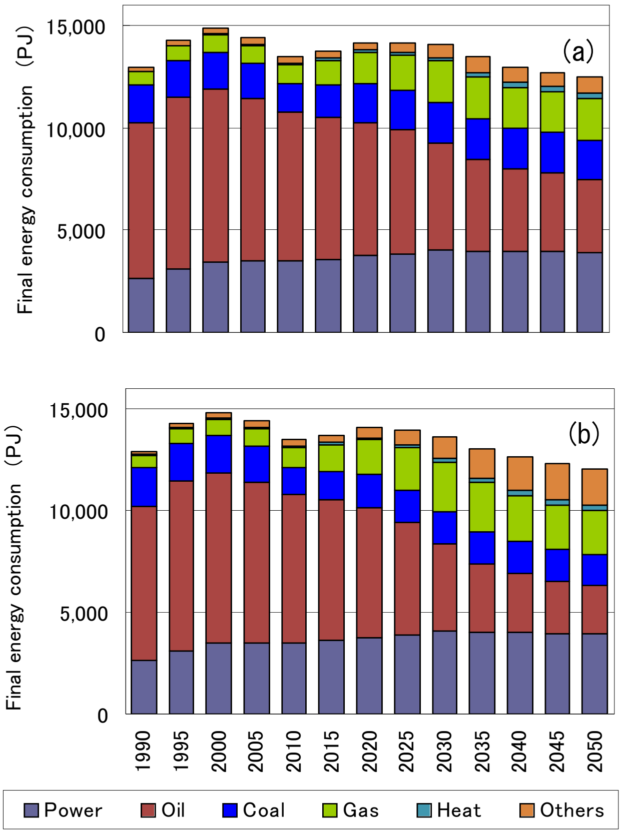

Fig.7 Final energy consumption in (a) Base case and (b) NuoutTax case

3.3. Electric power generation

Figure 8 shows that electric power generated has a peak in 2030 and then gradually decreases to 2050 for all the cases. In Nuout case, that is, the nuclear phase out without CO_2 constraint, nuclear power generation is very small in 2050 and coal fired power generation becomes the base of the power source in Japan.

In NuoutTax case with the CO_2 constraint, oil and coal fired power generation almost disappears after 2025 and LNG fired power generation including combined heat and power (CHP) becomes the main component of the power source. In 2050, LNG supplies approximately 70 % of the total power generated. In addition, PV is increasing continuously and generates 9 % of the total power supply in 2050.

3.4. CO_2 emissions

Figure 9 shows the CO_2 emissions in each case. In Base case, the CO_2 emissions decrease steeply to 890 million t/yr in 2050. However, the CO_2 emissions remain almost steady at the present level to 2050 in Nuout case due to the replacement of nuclear power generation with coal fired power generation.

On the contrary, the CO_2 emissions decrease to 830 million t/yr in 2050 in NuoutTax case. This reduction is mainly due to the large expansion of LNG. In addition, carbon capture and storage (CCS) is introduced after 2020 in this case. The amount of CCS gradually increases and then the total CO_2 emissions become 710 million t/yr with the introduction of CCS in 2050. This CO_2 emission level corresponds to approximately 40 % reduction of CO_2 as compared to that in 1990.

It is noted that the carbon tax assumed in NuoutTax case (1000 \$/t-CO_2 after 2035) is in agreement with the marginal abatement cost of CO_2 by Komiyama et al. [1], that is, approximately 1200 \$/t-CO_2 in 2050.

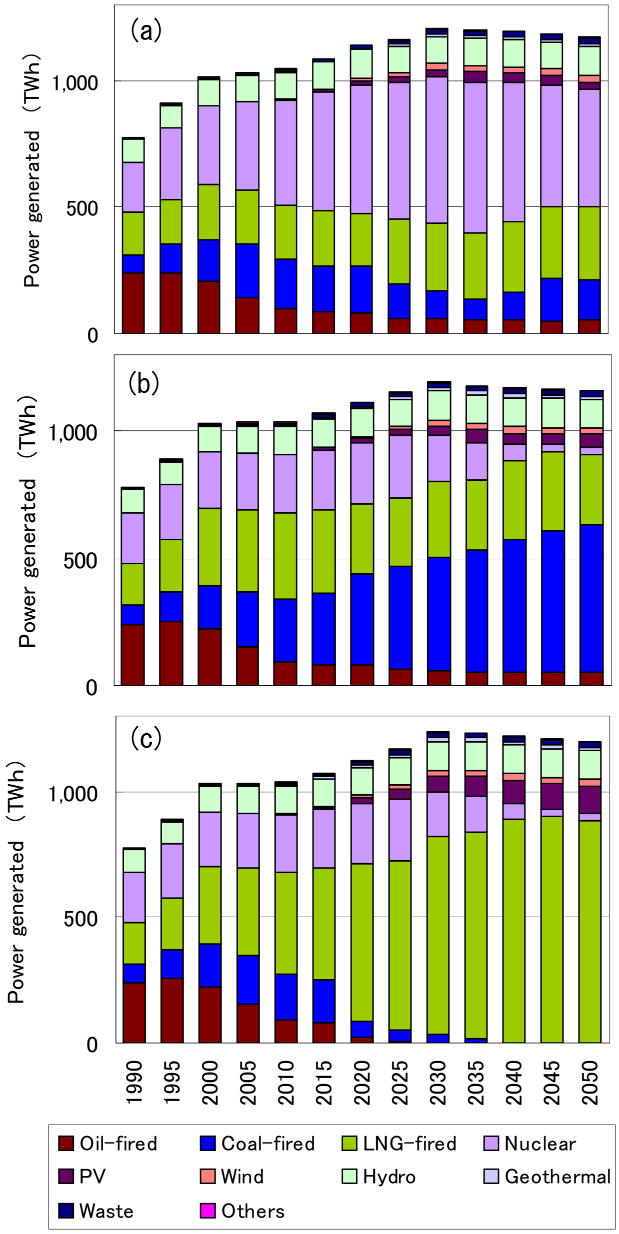

Fig.8 Electric power generated in (a) Base case, (b) Nuout case and (c) NuoutTax case

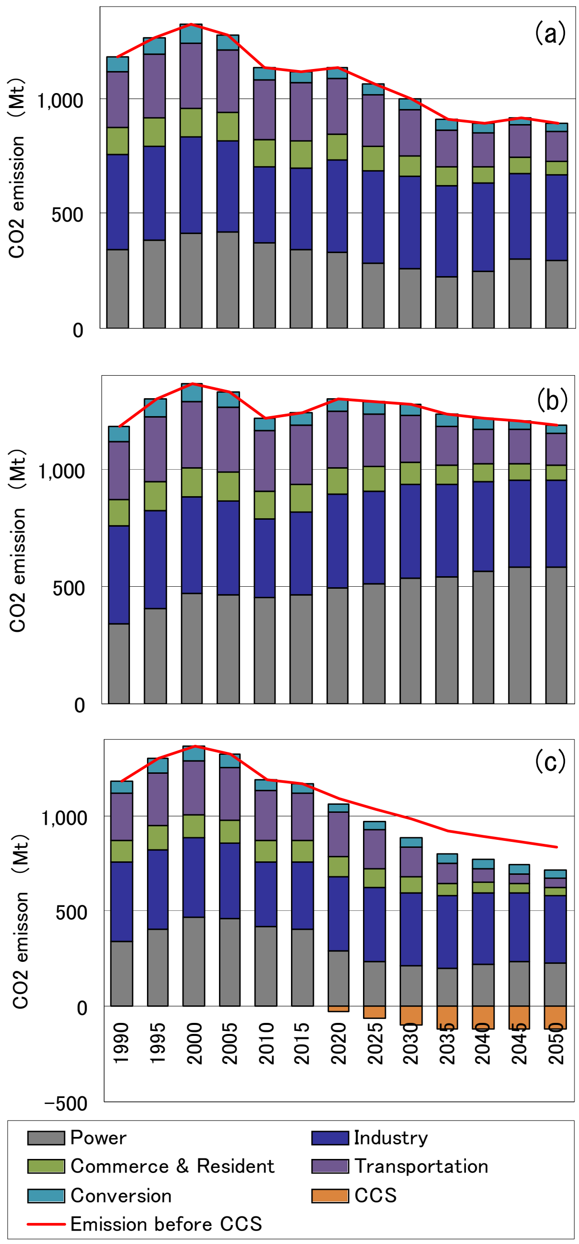

Fig.9 CO_2 emissions in (a) Base case, (b) Nuout case and (c) NuoutTax case

3.6. Fossil fuel import cost and total energy system cost

Currently, almost all the Japanese fossil fuel supply is that from imported fuels. Figure 10 shows results for total fossil fuel import cost. The fossil fuels include oil, coal and natural gas with those import price shown in Fig. 1

Figure 10 also shows differences of the fossil fuel import cost between Base case and Nuout case, and between Base case and NuoutTax case. These differences mean additional costs for the nuclear phase out. In Nuout case, the additional cost gradually increases to approximately 22 billion \$/yr in 2040. In NuoutTax case, this cost continuously increases to approximately 50 billion \$/yr in 2040 and then shows a plateau.

Total energy system cost was also estimated for these cases in 2040. In Base case, the total energy system cost is approximately 693 billion \$/yr. The total cost in Nuout and NuoutTax cases is 1.7 % and 6.2 % higher than that in Base case, respectively. This system cost evaluation excludes the tax burden in NuoutTax case.

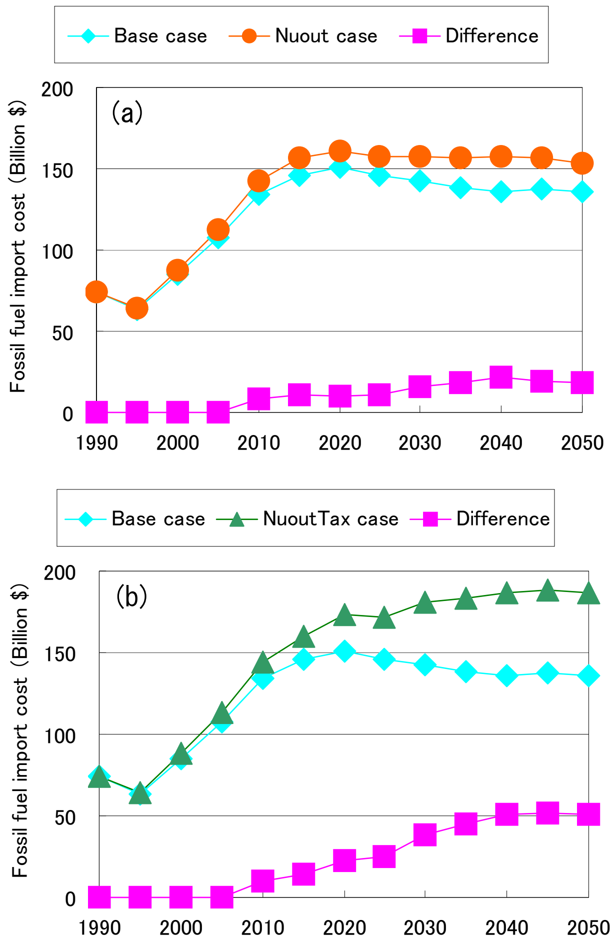

Fig.10 Fossil fuel import cost in (a) Nuout case and (b) NuoutTax case

4. Conclusion

This study indicated that the trend in nuclear power generation have significant influences on the primary energy supply portfolio and the CO_2 emissions in Japan. If the nuclear phase out and no CO_2 constraint are assumed (Nuout case), coal fired power generation drastically increases. Therefore, the CO_2 emissions do not decrease and stay at the present level until 2050.

On the contrary, LNG becomes the main energy source and PV and CCS are also introduced on a large scale due to the CO_2 constraint (NuoutTax case). In this case, the CO_2 emissions in 2050 are reduced to approximately 40 % of those in 1990.

The fossil fuel import costs were assessed for these cases. The additional cost is approximately 22 billion $/yr and 50 billion $/yr in 2040 for the nuclear phase out without and with the CO_2 constraint, respectively. It was also estimated that the total energy system cost in Nuout and NuoutTax cases is 1.7 % and 6.2 % higher than that in Base case, respectively.

To redesign "best energy mixture" in Japan, it is necessary to reconsider various factors comprehensively such as self-sufficiency in energy, energy resource import cost, variety of energy source, and the reduction of CO_2 emissions.

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