

Prospective on Policies and Measures for Realizing a Secure, Economical and Low-Carbon Energy System

—Taking the Effects of the Great East Japan Earthquake into Consideration

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ABSTRACT

The Great East Japan Earthquake devastated the eastern regions of Japan on this March. Due to the nuclear accident caused by the earthquake, Japan's Cabinet stated to revise energy policies. This article aims at investigating whether we could establish a secure, economical and low-carbon energy system taking account of the serious situation after the Earthquake. For this purpose, we first evaluated possible technology options along with economic options. Then we integrated these options in a computable general equilibrium model for Japan so as to evaluate the impacts to national economy. As results, we quantified the relationships between energy security, quality of life and CO₂ emissions.

Keywords: The Great East Japan Earthquake, Energy Policies, Computable General Equilibrium Model, Technology Options, Quality of Life, CO₂ Emissions

1. Introduction

The basis of sound energy policy is to realize a secure, economical and environmentally sound energy system. In the Basic Plan of Energy put forward by the Japanese Cabinet in 2010, nuclear energy is anticipated to play a significant role in ensuring a stable supply of energy and reducing CO₂ emissions in Japan. The Basic Plan of Energy proposes to build 14 new nuclear power plants, and to increase the average operating rates of these plants to 90% by 2030. However, on March 11, 2011, the Great East Japan Earthquake devastated the eastern regions of Japan. This earthquake, and the subsequent tsunami, cut off all power, including emergency backup power, to Tokyo Electric Power Company's Fukushima Dai-ichi Nuclear Power Plant, causing a critical situation. At present, the situation remains uncertain, and we can only hope for a speedy resolution and recovery. This nuclear accident, the most serious in Japanese history, will inevitably affect the country's future plans for nuclear energy, and the government of Japan may have to revise the Basic Plan of Energy itself. This article aims at investigating future energy scenarios and CO₂ emissions quantitatively.

2. Evaluation of Energy Policies by Using Computable General Equilibrium Model

We developed a computable general equilibrium (CGE) model for Japan, on the basis of Ichioka's analysis [1,2]. We used this model to evaluate the effects of various scenarios on the national economy. In this CGE model, households choose between present consumption and savings to maximize their utility. The goods and services available for present consumption are grouped into 19 categories, as shown in **Figure 1**. The utility of consuming these 19 types of goods and services is expressed by using the Cobb-Douglas function given in Equation (1). The present utility, consisting of the present consumption and leisure, is expressed by a constant elasticity of substitution (CES) function given in Equation (2). Finally, the utility integrating the present and future consumption is expressed by another CES function given in Equation (3).

$$X_i = \prod_{j=1}^{19} X_{ij}^{\lambda_{ij}} \quad (1)$$

X_i : Composite consumption of goods and services by the i th income bracket.

		1	2	...	18
	1				
	2				
Decrease by Energy saving	3				
	4				
	5				
Increased cost	6				
	7				
	8				
	9				
	10				
	11				
	12				
Increased cost	13				
Decrease by Energy saving	14				
	15				
	16				
	17				
	18				
	19				

1	-200
2	200-250
3	250-300
4	300-350
5	350-400
6	400-450
7	450-500
8	500-550
9	550-600
10	600-650
11	650-700
12	700-750
13	750-800
14	800-900
15	900-1000
16	1000-1250
17	1250-1500
18	1500-

Brackets by income

Figure 1. Consumption and production sectors in our CGE model.

X_{ij} : Consumption of the j th good or service by the i th income bracket.

$$H_i = \left\{ \beta_i^{1/\sigma_{li}} l_i^{\sigma_{li}} + (1 - \beta_i)^{1/\sigma_{li}} X_i^{\sigma_{li}} \right\}^{1/\sigma_{li}} \quad (2)$$

H_i : Present consumption by the i th income bracket.
 l_i : Consumption of leisure by the i th income bracket.

$$U_i = \left\{ \alpha_i^{1/\sigma_{2i}} H_i^{\sigma_{2i}} + (1 - \alpha_i)^{1/\sigma_{2i}} C_{Fi}^{\sigma_{2i}} \right\}^{1/\sigma_{2i}} \quad (3)$$

U_i : Utility of the i th income bracket.
 C_{Fi} : Future consumption by the i th income bracket.

Households are classified into 18 brackets according to their annual income, from the lowest bracket receiving less than 2 million yen per year to the highest bracket earning more than 15 million yen per year. This classification is important in the current analysis for evaluating the economic impact on each income bracket. Since renewable energy and products with improved efficiency tend to be more expensive than ordinary products, households in higher income brackets can more easily afford these products than households in lower income brackets. Consequently, the impact on a household depends on annual income. We should exercise due care to minimize the economic impact on lower income households.

On the other hand, firms determine the factors of production, labor and capital inputs in order to maximize their profit, as shown by Equation (4). At the same time, intermediate demand in each industry is determined from the Leontief production function given in Equation (5), in which the relations between 39 types of goods and services are expressed in an input-output table (Figure 2).

$$VA_j(L_j, K_j) = A_j L_j^\alpha K_j^{1-\alpha} \quad (4)$$

L_j : Labor input of the j th industry.

	Agriculture, forestry and fishery	21	Electric machinery
1	Limestone	22	Automobile
2	Coal	23	Transport machinery
3	Oil	24	Precision machinery
4	Natural gas	25	Other manufacturing
5	Other minerals	26	Construction
6	Food	27	Electricity
7	Textile	28	Gas
8	Wood products	29	Heat
9	Pulp & paper	30	Water & Sewage
10	Printing	31	Waste disposal
11	Chemistry	32	Commerce
12	Petroleum products	33	Finance & Insurance
13	Coal products	34	Real estate
14	Ceramic products	35	Transport
15	Cement	36	Broadcasting
16	Iron & steel	37	Service
17	Non-ferrous metals	39	Private non-profit service
18	Metal products		
19	General machinery		

Figure 2. Industrial sectors in input-output table.

K_j : Capital input of the j th industry.
 VA_j : Value-added production of the j th industry.
 α : Optimal share of labor cost in the factors of production.

$$Q_j = \min \left\{ VA_j(L_j, K_j) / a_{0j}, X_{1j} / a_{1j}, \dots, X_{nj} / a_{nj} \right\} \quad (5)$$

Q_j : Production of the j th industry.
 a_{ij} : Input coefficient from the i th to the j th industry.

For the case where an industrial sector is deploying energy-saving and renewable products for households, production values increase in electric machinery, precision machinery, transportation and the like. In contrast, households consume less electricity and gasoline as a result of efficiency improvements, and thus the production values in industrial sectors of electricity and petroleum products decrease. Consequently, complicated repercussion effects are observed in many industrial sectors.

An additional consideration is that governments will impose various types of taxes in order to meet targets for final demand and public investment.

Finally, we compute the equilibrium points, at which the supply and demand of all goods and services, and of factors of production, are equal (Figure 3).

3. Scenarios of Energy Supply, CO₂ Emissions and Living Standards in 2020 and 2030

In this section, we describe five possible scenarios, and

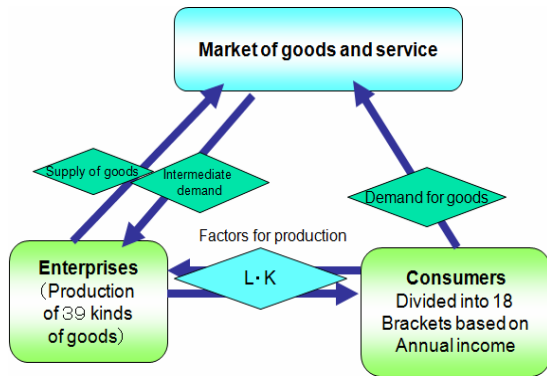


Figure 3. Conceptual figure of general equilibrium.

use the proposed CGE model to evaluate living standards and the amount of domestic CO₂ emissions in 2020 and 2030. The five scenarios assume the adoption of several energy-saving and renewable technologies with either increased or decreased use of nuclear power plants. Next we describe on assumptions for the five scenarios of the economic growth and distributions of power generation in 2020 and 2030, as follows (Figure 4).

Case 1: The nominal case.

The nominal case does not adopt any measures to reduce greenhouse gas emissions. GDP is assumed to grow at an annual rate of 1.3% from 2005 to 2020 and 0.5% from 2020 to 2030. We assume that decrease of national

population and deepening maturity of economy leads to the lower growth rate from 2020 to 2030.

Case 2: Increasing nuclear plants.

With the same GDP growth rate as in Case 1, in Case 2 we assume that 8 and 14 new nuclear power plants will have been constructed by 2020 and 2030, respectively; note that the 6 reactors at the Fukushima Daiichi Nuclear Power Plant are assumed to be decommissioned by 2020. We also assume that the operating ratio of all nuclear plants will have improved to between 85% and 90% by 2020, in accordance with the Basic Plan of Energy. Moreover, generation from solar power systems is assumed to increase to 28 GW in 2020 and 53 GW in 2030.

Case 3: Maintaining nuclear plants.

Assumptions are same as Case 2 except we assume that no further construction of nuclear plants will occur in future.

Case 4: Decreasing nuclear plants.

We assume that no further construction of nuclear plants will occur in the future, and that all other existing nuclear power plants will be decommissioned after 30 years of operation. Power shortages resulting from closing the nuclear plants will be compensated for mainly by coal, oil and natural gas power plants. Solar power generation is assumed to increase to 38 GW in 2020, and 80 GW in 2030. All other assumptions are identical to Case 2.

Case 5: Abolishing all nuclear plants.

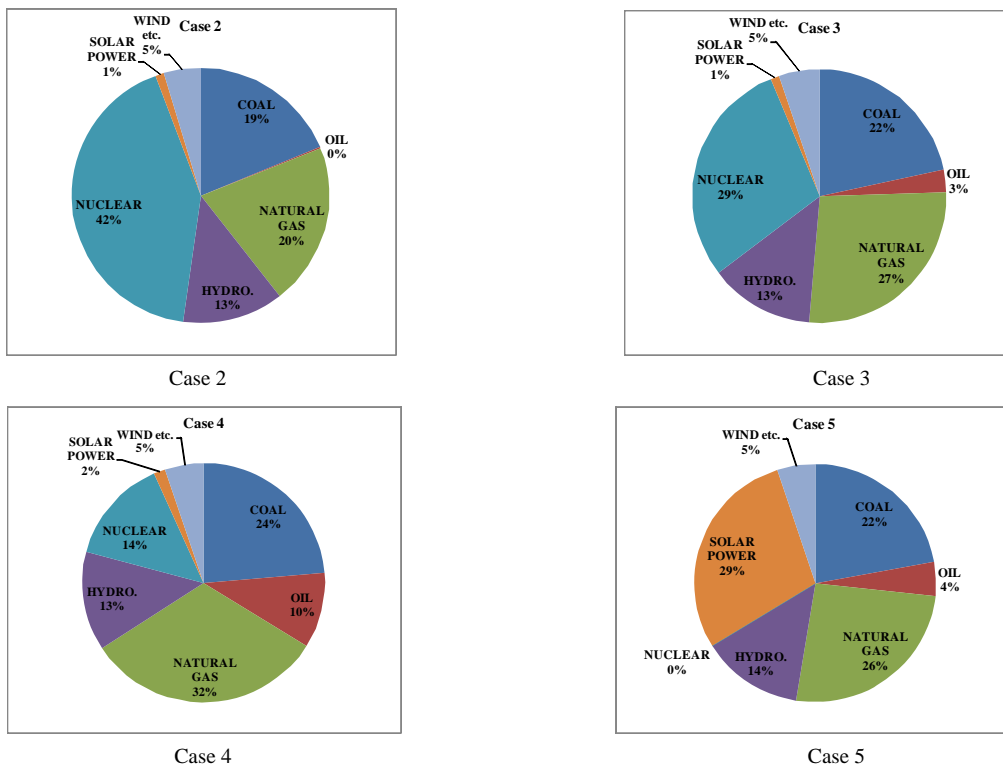


Figure 4. Distribution of power sources for Cases 2 - 5 in 2020.

Assumptions are the same as Case 2 except for the following. We assume that no further construction of nuclear plants will occur in the future, and that all other existing nuclear power plants will be decommissioned by 2020. Energy generated by solar power systems is assumed to increase to a level of 287 GW in 2020 and 2030, replacing all of the power generated by the present nuclear power plants.

Based on the estimated lifetime of nuclear power plants, their output capacity over the next 30 years is shown in **Figure 5**.

Next we show policies and measures adopted in this analysis for energy efficiency improvement, excluding the power generation sector, in both 2020 and 2030. We evaluate these cases both with and without the energy-saving measures as described in (1), (2) and (3).

1) The percentage of next-generation energy efficient homes (1999 standard) as a stock base is assumed to be 22% in 2020 and 48% in 2030, in accordance with the National Institute of Construction.

2) The percentage of next-generation passenger cars as a stock base is assumed to be 40% in 2020 and 50% in 2030. Next-generation passenger cars are hybrid, plug-in hybrid, electric, fuel cell vehicles and the like.

3) The “Top runner” system is assumed to be continued for domestic electrical appliances and automobiles.

4) Natural gas is assumed to replace 80% (relative to 2005 levels) of petroleum products and fuel, including heavy oil, used by all manufacturing sectors (except the petrochemical industry).

5) Promoting modal shift: based on input-output analysis of distribution, CO₂ emissions in the transportation sector are assumed to be cut by up to 44%.

6) Promoting energy savings in industrial sectors: in accordance with the law promoting energy conservation, the annual improvement of energy intensity in each industry is assumed to be 1%.

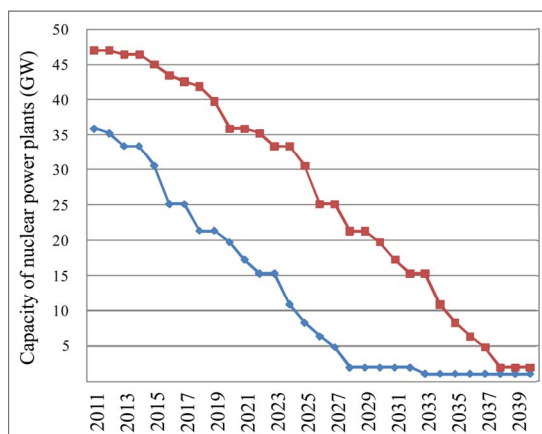


Figure 5. Power capacity of existing nuclear power plants over their estimated lifetime.s

For solar power generation systems, we assume that their cost will decrease according to the estimate given by Yamada *et al.* [3] as shown in **Table 1**. A methodology to evaluate the cost of future power generation systems was reported and published in a proceedings of 2011 World Engineers’ Convention.

We used the CGE model to estimate the reduction in CO₂ emissions from energy consumption in comparison with the 1990 emissions level. **Figures 6** and **7** show the estimate results for each case in 2020 and 2030, respectively.

Table 1. Estimate of future cost of solar power generation systems [3].

	(Yen/W)			
	2011	2015	2020	2030
Module	150	120	100	50
Balance of the system	200	150	100	70
Total system	350	270	200	120

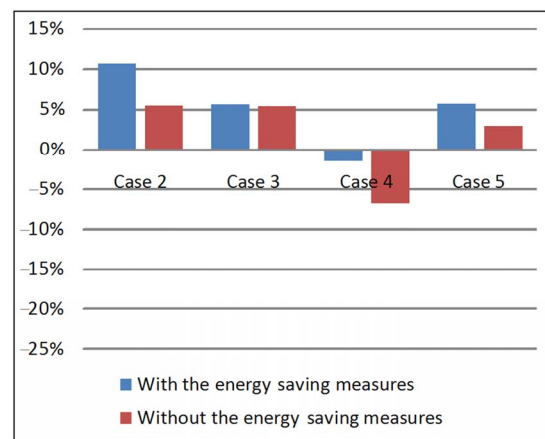


Figure 6. Reduction of CO₂ emissions in 2020 compared with 1990.

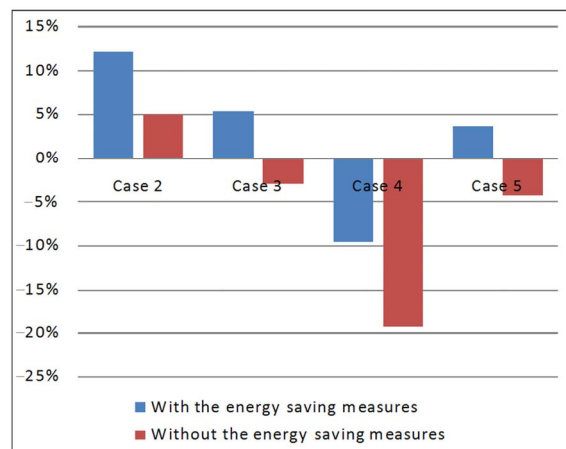


Figure 7. Reduction of CO₂ emissions in 2030 compared with 1990.

The results indicate that decreasing the use of nuclear energy has a large impact on CO₂ emissions. Namely, the difference in the CO₂ reduction, between the case of increasing nuclear energy and the case of decreasing nuclear energy, is approximately 12% in 2020 and 22% in 2030.

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Next, we show the increases and decreases in household welfare values. **Figures 8** and **9** show the estimated differences in welfare values per household for each case compared with Case 1 for 2020 and 2030, respectively.

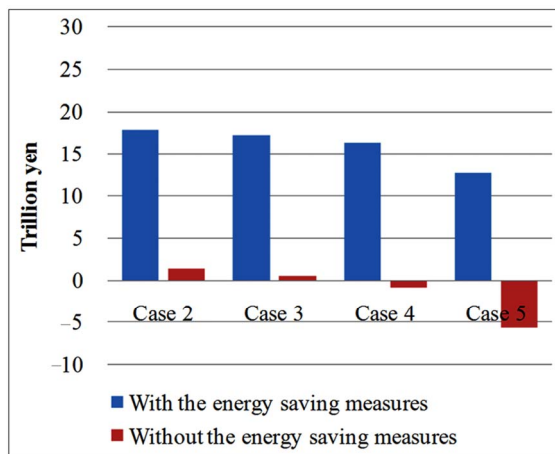


Figure 8. Changes in household welfare values in 2020.

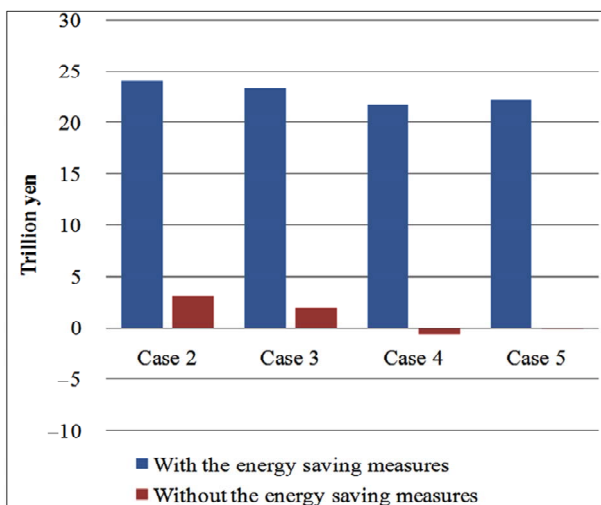


Figure 9. Changes in household welfare values in 2030. Figures 8 and 9 express the differences from Case 1, the no reduction case.

Changes in welfare are translated from changes in utility by using the concept of equivalent variation. Specifically, the welfare changes show changes in utility, based on the concept of equivalent variation, in which the utility changes are expressed in terms of the price of goods and services before the change. We cannot express changes in household welfare in terms of only disposable income, since the prices of goods and services are different depending on each case. Hence, we use household welfare values with equivalent variation.

Values of household welfare in Case 2 are higher than those in Case 5 in 2020. However, household welfare values for Case 5, in which all nuclear power plants are decommissioned and replaced with solar power generation systems, are even higher than those for Case 1, in which no measures are taken to reduce CO₂ emissions.

Although values of household welfare for Case 2 are also higher than those for Case 5 in 2030, the difference is much smaller than in 2020. This smaller difference in household welfare is because the costs of solar power generation systems and batteries are lowered (see **Table 1**) through research and development of these technologies. To confirm this point, in **Figures 10** and **11** we show percentage changes in the prices of consumption goods for households in 2020 and 2030, respectively.

Unless we are unable to deploy the energy-saving technologies listed in (1), (2) and (3) in Chapter 3, the prices of all consumer goods centered on electricity escalate in 2020. This escalation is a consequence of deploying enough solar power generation systems to produce nearly 300 GW of electricity by means of a feed-in-tariff. In contrast, the increase in the price of electricity and other goods becomes smaller in 2030, even though these solar power generation systems produce nearly 300 GW of power. This trend is mainly due to the effect of reducing the cost of solar power generation systems, as shown in **Table 1**.

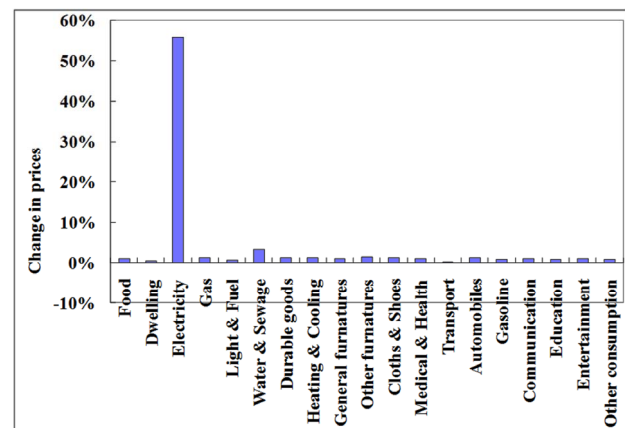


Figure 10. Changes in prices of consumption goods of households in 2020.

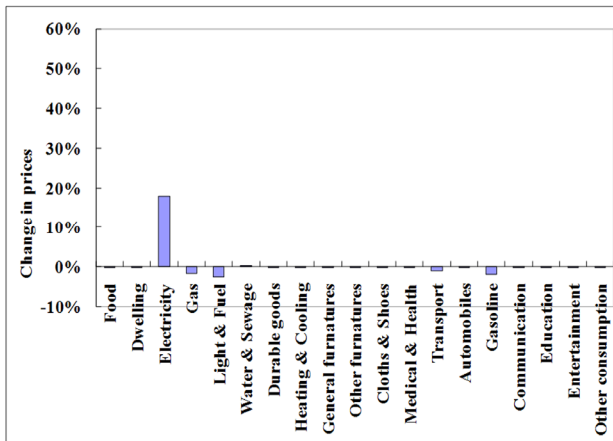


Figure 11. Changes in prices of consumption goods of households in 2030. Figures 10 and 11 depict changes in prices from Case 1.

Finally, we compare household welfare values in 2030 for all income brackets under Case 2 and Case 5 (Figures 12 and 13). These figures show that household welfare values will increase regardless of the existence of nuclear power plants, as long as the energy efficiency of final consumption is improved using the measures (1), (2) and (3) in Chapter 3. Therefore, promotion of energy conservation is the most significant factor in establishing a low carbon society.

The following implications are deduced from the above analyses:

- Cases 2 and 3, in which we increase or maintain the number of nuclear power plants, are superior in improving household welfare and decreasing CO₂ emissions. However, these cases are questionable from the perspectives of environmental safety and security. Especially, now that public acceptance has been lowered by the accident at the Fukushima Daiichi Nuclear Power Plant.
- Although Case 4, in which we decrease nuclear power plants, is inferior to Cases 2 and 3 in terms of household welfare values, the difference is small. CO₂ emissions are, however, drastically increased in Case 4, which is contradictory to the goal of establishing a low carbon society in Japan.
- CO₂ emissions are reduced to some extent in Case 5, in which we decommission all nuclear power plants within five years. Case 5 is also not problematic from the perspectives of environmental safety and security. However, introduction of a large number of solar power generation systems suppresses household welfare due to the rapid escalation of electricity prices. If the cost of solar power generation systems can be decreased as shown in Table 1, there will be almost no adverse effect on households.

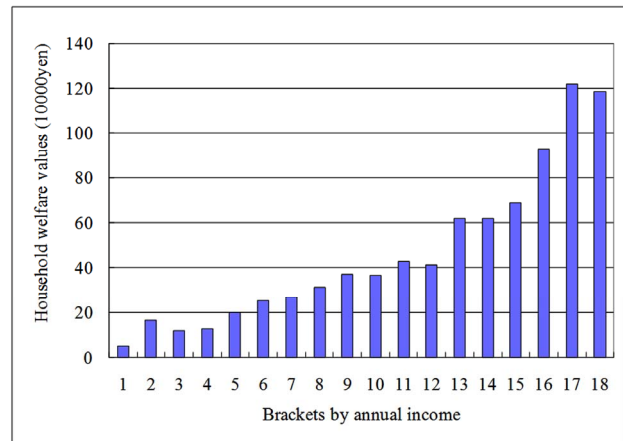


Figure 12. Changes of household welfare values in individual income brackets for Case 2.

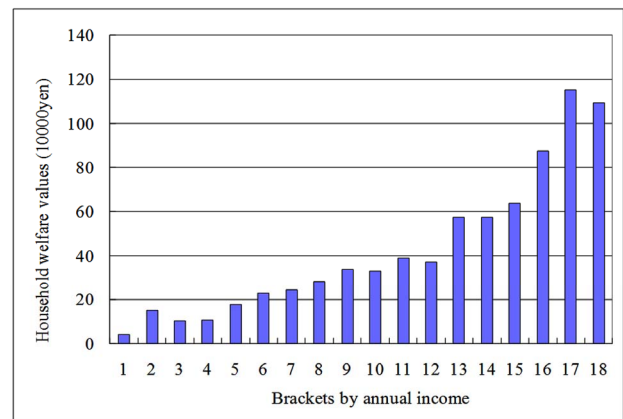


Figure 13. Changes of household welfare values in individual income brackets for Case 5. Figures 12 and 13 depict the change in household welfare values relative to Case 1, and we assume promotion of energy-saving measures (1), (2) and (3) in Chapter 3.

4. Conclusions

This article aimed at investigating energy policies and measures to establish a low carbon society. For this purpose, we used the computable general equilibrium (CGE) model for Japan, so as to conduct a comparative analysis of the effects of increasing and decreasing the number of nuclear power plants on the national economy and CO₂ emissions. We also used the model to evaluate the effects of deploying renewable energy and energy-saving technologies. As a result, we found that a decrease or abolishment of nuclear power plants has a serious negative impact on CO₂ emissions.

Next we evaluated the impact of energy policies on households' utility. The computed results imply that the utilities of households could be considerably improved by the spread of energy-saving products, such as high-efficiency electrical appliances and automobiles. Thus,

measures to promote the spread of these products are crucial, regardless of the increase or decrease of nuclear power plants.

Now that trust in nuclear energy has been severely damaged as a result of the accident at the Fukushima Daiichi Nuclear Power Plant, it is inevitable that energy policies must be revised. With present technologies and institutions—regardless of whether nuclear power plants are increased, maintained, decreased or decommissioned—no ideal solution exists that offers environmental safety and security, benefits to the economy and low carbon emissions. Thus, we need technological and institutional innovations in order to realize a sustainable energy system in the long term. These innovations include reducing the cost of solar power generation technologies, improving energy efficiency, integrating infor-

mation technology with the energy system to create a smart grid, and introducing renewable energy technologies.

REFERENCES

- [1] O. Ichioka, “Applied General Equilibrium Analysis,” Yuhikaku Publishing Co., Tokyo, 1991.
- [2] R. Matsuhashi, K. Takase, T. Yoshioka, Y. Imanishi and Y. Yoshida, “Sustainable Development under Ambitious Medium Term Target of Reducing Greenhouse Gases,” *Forum on Public Policy: A Journal of Oxford Round Table*, Vol. 2010, No. 3, 2010, pp. 1-11.
- [3] K. Yamada, T. Inoue and K. Waki, “Future Prospects of Photo-Voltaic Systems for Mitigating Global Warming,” *Proceedings of 2011 World Engineers’ Convention*, Geneva, 5-8 September 2011.