The Economic and CO_2 Emission Effects of Japan's Denuclearization and Renewable Energy Promotion after the Tohoku-Pacific Ocean Earthquake

— Some Implications resulted from the Integrated Model of Multi-sectoral Macroeconomy and Energy —

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Abstract: *This paper assesses the economic and CO_2 emission effects of Japan's denuclearization and renewable energy promotion after the Tohoku-Pacific Ocean Earthquake. Our analysis is based on a non-equilibrium dynamic model, the MSME model that is an integrated model of multi-sectoral macroeconomy and energy, and some model simulation outputs of the economic and CO_2 emission effects under some alternative scenarios that could be taken by the government's policy after the Earthquake.*

As the government is investigating the way to reduce Japan's dependency on nuclear power by promoting alternative energy sources in the short term, the simulation period is set to be from 2011 to 2020. In our model simulation, we set some key assumptions of regarding components of power generated by power source. The BaU case is assumed that the number of nuclear power plants in operation decreases with the plant life-time (40 years), and the other seven cases are set up by various combinations of the number of nuclear power plants and alternative energy sources to be balanced between Japan's electricity demand and supply annually to the year 2020.

Based on our model simulation outputs, we examine the impacts of increase in the electricity prices by the substitution for nuclear power and by renewable energy introduction not only on macroeconomic variables, but also on CO_2 emission, energy consumption and production amounts by 17 industrial sectors. In addition, we evaluate the effect of production inducement and increase in the electricity prices by the introduction of renewable energy, and its impacts on each industry in Japan.

Keywords: Economic and Energy Model, Economic Instruments, Simulation, Low-carbon Economy.

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1. INTRODUCTION

After the Tohoku-Pacific Ocean Earthquake, Japan has been reducing its nuclear power generation. Policy makers must design some alternative power supply scenarios for the lost power supply generated by nuclear power plants, simultaneously, taking account of examining the differences of macroeconomic burdens and industrial economic effects among the scenarios.

Economy-energy models can be generally classified as top-down models or bottom-up models. Furthermore, top-down economic models can be classified as CGE models or econometric macroeconomy models. There are CGE models in which behavioral equations are based on maximizing utility of consumers and profits of producers. Each market equilibrium in a CGE model is balanced by pricing mechanism. Thus, each solution in a CGE model will be optimized. For all that, some people have discussed weak aspects of CGE models that such simulation results did not necessarily correspond to the realities (Kawasaki, 1999). Meanwhile, some people have indicated weak points of macro econometric models, according to Lucas (Lucas, 1976), that the main cause of the failure of the econometric models in prediction and policy analysis was the assumption of structural invariance of the parameters of the estimated models. It was also shown that the expectations of economic agents were likely to affect the structure of the model used for policy analysis, and therefore to distort the outcomes. An econometric model specifies the statistical relationships that are believed to hold among the various economic quantities pertaining to a particular economic phenomenon.

In this paper, however, since macro econometric models can represent many causality relationships among economic and energy variables of real Japanese economy, thus we will build a non-equilibrium dynamic econometric model to have a grasp of cause-effect relationships between alternative policies and simulation results.

The MSME (Multi-sectoral macro economy) model that we have developed in our study is an integrated economy-energy non-equilibrium econometric model that simulates the interaction of Japan's macroeconomic performance and energy supply-demand. We built our hybrid economy-energy econometric model based on historical data between 1991 and 2008 to evaluate various quantitative impacts on macroeconomic and the industrial sectors by alternative energy policies after the quake.

With regard to the structure of this paper, firstly, we start to describe the outline of our hybrid economy-energy econometric model. Secondly, we explain the method of setting eight cases, which are differentiated by dependency on nuclear power and renewable energy power between 2011 and 2020, and of running the model simulation. Thirdly, we analyze simulation results and prove some policy implications regarding GDP (gross domestic products), CO_2 emission, employment, and production prices in Japan.

2. THE HYBRID ECONOMY-ENERGY MODEL

2.1 Outline of the hybrid economy-energy model

We have built the hybrid economy-energy model that is comprised of a multi-sectoral macroeconomic model and an energy model, both of which incorporate the non-equilibrium dynamic structure. The sample period of the behavioral equations is from 1991 to 2008 because of the data limitations. The model describes not only energy demand-supply, but also economic and industrial structure in Japan (see Figure 1). This model is disaggregated into 17 industrial sectors. In this study, we set the simulation period from 2011 to 2020, and will be able to have some model simulation results in terms of energy consumption, CO_2 emission and so on, of macroeconomic and industrial sectors, in some alternative scenarios of power source composition in the short-term. Details of each model and the model integration will be described in the following section.

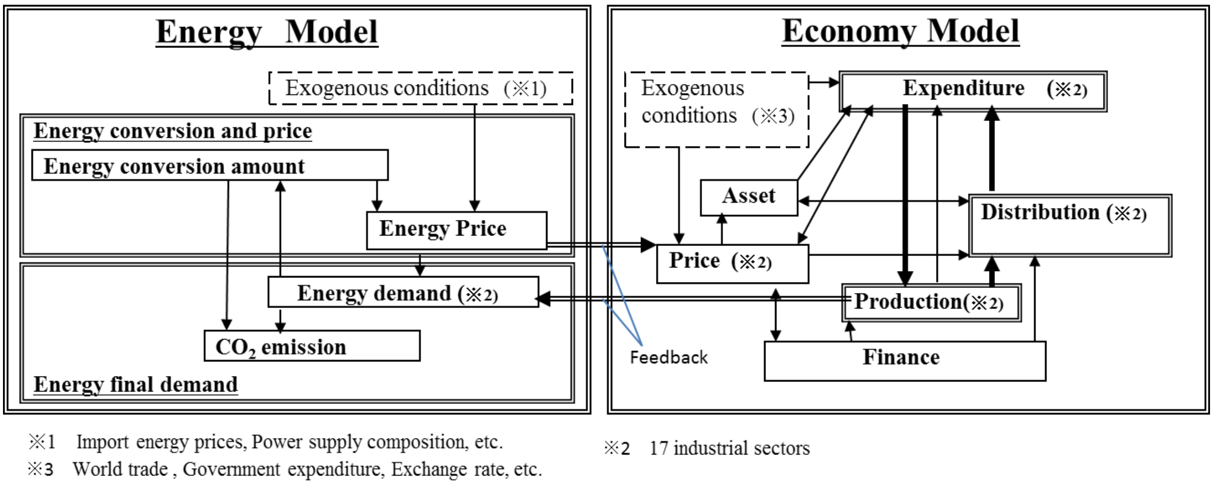

Figure 1 Outline of the hybrid economy-energy econometric model

2.2 Multi-sectoral macroeconomic model

We have developed the multi-sectoral macroeconomic model that has been basically referred to J-MACRO model (Takeshita, 2003), which is a multi-sectoral econometric model of non-equilibrium dynamic type developed for the Japanese economy. Our model is a large-scale model consisting of approximately 519 equations, all of which we have re-estimated by using annual data on the basis of the System of National Accounts 1993 (SNA93) by 2000 price (Cabinet Office, 2010, Cabinet Office, 2007) between 1991 and 2008 (see Table 1). The basic structure of our model is shown in Figure 1. The macroeconomic model describes the Japanese economy with equivalence of three aspects (production, distribution and expenditure), and is comprised of 6 blocks: (1) expenditure block; (2) production block; (3) distribution block; (4) price block; (5) asset block; and (6) finance block. All the blocks are interdependent, and are solved simultaneously and iteratively by the Gauss-Seidel method until the model converges on a solution. This model is not only a macroeconomic model but also a semi-macro economic model that is disaggregated into 17 industrial sectors as shown in Table 1, considering the availability of a consistent set of time series data, and describes the inter-industry linkages and the decision rules for economic variables by each sector. The model describes appropriately three aspects of the economy: production, distribution, and expenditure, and also explicitly represents almost all the short-term economic impact paths of fiscal policy, including those through the price and monetary side as well as those through the real side of the economy.

The formulations of the major economic variables in the expenditure sector are shown as follows:

(1) Household's consumption function

The households' consumption function is derived from the life cycle/permanent income hypothesis based on microeconomic theory and the adaptive expectations formation hypothesis of Friedman regarding how consumers expect their permanent income. YW is the employees' income, $MAHT$ is the household financial asset, $MLHT$ is the household financial liabilities, $PHCP$ is the household's consumption deflator, RAL is the lending rate, a is the parameters. Thus, HCP (the households' consumption) is equal to:

$$HCP = a_1 \times \frac{YW}{PHCP} + a_2 \times (1 + RAL)\left(\frac{MAHT(-1) - MLHT(-1)}{PHCP}\right) + a_3 \times HCP(-1) + a_4 \tag{1}$$

(2)Housing investment

The housing investment function is derived from the life cycle/permanent income hypothesis based on microeconomic theory. YW is the employees' income, $PHCP$ is the household's consumption deflator, KH is the housing stock. Thus, IH (housing investment) is equal to:

$$IH = f\left(\frac{YW / PHCP - YW(-1) / PHCP(-1))}{YW / PHCP}, KH(-1) + KH(-2)\right) \tag{2}$$

(3) Capital investment by industry

Capital investment by industry is determined by the investment function based on the acceleration principle taking into consideration the user cost of capital based on the neoclassical investment theory. X_j is the productions, KP_j is the capital stock, PIX_j is the production price of industry j, UC_j is the capital cost of industry j, BS_j is the operating surplus of industry j. Thus, IP_j (capital investment of industry j) is equal to:

$$IP_j = f\left(X_j, X_j - X_j(-1), KP(-1), UC_j / PIX_j\right) \tag{3}$$

(4)Export and Import

Export is estimated for each commodity as a logarithmic linear function of its relative prices and a given foreign demand. WTD is the world trade amount, PEX_i is export price of goods i, $PIMN_i$ is the import price of goods i. Thus, EX_i (exports of goods i) is equal to:

$$\log(EX_i) = f\left(\log(WTD), \log\left(\frac{PEX_i}{PIMN_i}\right)\right) \tag{4}$$

Import is estimated for each commodity as a logarithmic linear function of domestic demand by commodity, relative prices by commodity, and a given foreign production ratio by commodity. DC_i is the demands of goods i , PIM_i is the import price (tax included) of goods i, PCX_i is the production price of goods i. Thus, IM_i (imports of goods i) is equal to:

$$\log(IM_i) = f\left(\log(DC_i - EX_i), \log\left(\frac{PIM_i}{PCX_i}\right), FR_i\right) \tag{5}$$

(5)Gross domestic product

The real GDP is determined by identity as the sum of real final demand components. Government expenditures such as public investment are given exogenously as policy variables. CP is the private final consumption, CG is the government consumption, IH is the housing investment, IP is the capital investment, IG is the public investment, JP is the Goods in stock, JG is the public goods in stock, EX is the Exports, IM is the

Imports. Thus GDP (Gross domestic product) is equal to:

$$GDP = CP + CG + IH + IP + IG + JP + JG + EX - IM \quad (6)$$

Table 1 Outline of the multi-sectoral macroeconomic model

Area	Japan
Time period	・Annual data ・Estimation period : 1991 -2008(18 years)
Model scale	・Number of equations : 519
Basic structure	・Non-equilibrium dynamics ・Markup method
Industrial sectors	・Combination of commodity×commodity(SNAIO) and industry×industry(SNA) ・17 industrial classification: (1) Agriculture, forestry and fishery (2) Mining (3) Food and beverage (4) Textiles (5)Pulp, paper and paper products (6)Chemicals (7)Petroleum and coal products (8)Non-metallic mineral products (9)Basic metal (10)Fabricated metal products and machinery (11)Other manufacturing industries (12)Construction (13)Electricity, gas and water supply (14)Transportation and communication (15)Services and other tertiary industries (16)General government (17)Private non-profit institutions serving households
Consumption function	Life-cycle and permanent income consumption function
Production Function	Cobb-Douglas production function

2.3 Energy model

We have developed the energy econometric model that has been basically referred to the energy model (Nagata, 1995), which is based on pricing-mechanism and a multi-sectoral econometric model of non-equilibrium dynamic type developed for the Japan's energy demand-supply. Our energy model is a large-scale model consisting of approximately 383 equations, all of which we have re-estimated by using annual data on the basis of *Comprehensive Energy Statistics* (Ministry of Economy, 2011) and *EDMC Handbook of Energy & Economic Statistics in Japan* (Institute of Energy Economics, 2010) between 1991 and 2008 (see Table 2). This model describes Japan's energy demand-supply and comprises of two blocks: the energy conversion and price block, and the energy final demand block (see Nagata, 1995). All these blocks are interdependent. This energy model is disaggregated into 17 industrial sectors.

In this model, power supply composition and import energy prices, etc. are given as exogenous variables. Secondary energy prices and supply are determined by these exogenous variables and each energy demand (endogenous variables) .

Each energy consumption share is determined by relative prices of energy. Meanwhile, CO_2 emissions are estimated by final energy consumption.

Table 2 Outline of the energy model

Area	Japan
Time period	・Annual data ・Estimation period：1991-2008(18 years)
Model scale	・Number of equations：383
Basic structure	・Non-equilibrium dynamics
Classification of energy consumption	Industry classification： Comprehensive energy statistics -based 13 classification Transportation classification： Comprehensive energy statistics -based 9 classification Household and service classification： EDMC Handbook of energy & economic statistics in Japan-based 10 classification

2.4 Pricing mechanism of electricity in this model

In this model, electricity prices are determined based on general costing method. Firstly, total electricity supply is estimated by total electricity demand, capital costs, maintenance costs, and fuel costs (see Figure 2). In addition, the capital costs are estimated by the installed capacity and electricity supply source. Secondly, the total unit cost is determined by each cost. The electricity prices are given by the total unit cost. The Cost of renewable energy introduction is added to total unit cost in the model.

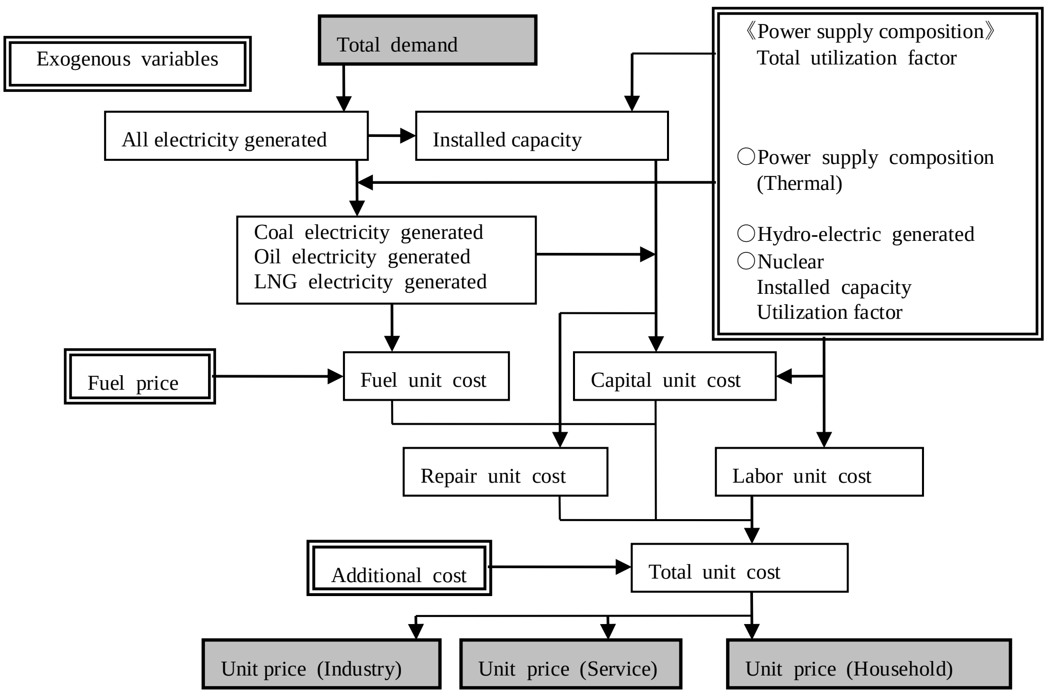

Figure 2 Flow chart of the pricing mechanism of electricity in the energy model

2.5 Linkage of the two models and model test

The hybrid economy-energy model has the feedback structure listed below (see Figure 1).

(1)Energy demand of 17 industries in the energy model is estimated by amounts of production in 17 industries in the multi-sectoral macroeconomic model. Energy demand of households in the energy model is estimated by disposable incomes in the multi-sectoral macroeconomic model.

(2) Intermediate inputs by the industrial sector are disaggregated into the energy part and non-energy part. Intermediate inputs by the industrial sector are estimated by energy costs by the industrial sector in the energy model.

Concerning the hybrid economy-energy model, we have conducted a final test of the model from 1991 to 2008 (estimation period) and confirmed that all of endogenous variables have a small margin (less than 5% of error) between the estimated values and the actual values.

3. DESCRIPTION OF MODEL SCENARIOS

In this study, we set the simulation period from 2011 to 2020 and assume that the lifetime of nuclear power plant would be 40 years. We also set two simulation scenarios; 1) nuclear power plants are shut down as required by the lifetime (A), and 2) nuclear power plants are not shut down (B) (see Table 3). As an alternative for nuclear energy, we set the case of selected thermal power and the case of renewable energy (photovoltaic power and wind power). In addition, for introducing renewable energy, we set the following assumptions: (1) the penetration rate increases linearly, (2) the penetration rate increases as the learning curve, (3) A massive penetration in the short-term.

We assume that A1 case is Business-as-usual (BaU) case as the most realistic. By assuming that renewable energy technologies are only produced in Japan, it will cause final demand of fabricated metal products and machinery sector increasing linearly to the increasing penetration of renewable energy.

Table 3 Conditions of the simulation

Case	Key assumptions	Alternative energy for nuclear power generation	
A1(BaU)	The number of nuclear power plants in operation decreases with the plant life-time (40years).	Thermal power generation (its component ratio of the total thermal power generation is fixed with the level in 2010).	
A2		Renewable energy introduction (Solar and wind power)	the penetration rate increases linearly .
A3			the penetration rate increases as the learning curve
A4			A massive penetration in the short-term
B1	The number of nuclear power plants in operation is fixed with the level as of September 2011.	Thermal power generation (its component ratio of the total thermal power generation is fixed with the level in 2010).	
B2		Renewable energy introduction (Solar and wind power)	the penetration rate increases linearly .
B3			the penetration rate increases as the learning curve
B4			A massive penetration in the short-term

4. RESULTS AND DISCUSSIONS

4.1 Impacts on GDP and the added value by the industrial sector

According to our simulation results, the average growth of GDP is 0.74%/year in the BaU case; it will be about 557 trillion yen in 2020.

In case A2-4 and B2-4, the amounts of renewable energy introduction are 7 million kW. Figure 3 shows the change ratio of GDP of other cases compared with the BaU case. By introducing renewable energy, it will reduce GDP change ratios by about 0.2% in the end of period. From this result, it proves that increasing penetration of renewable energy gives much greater effects on GDP than increase on productions of renewable technologies.

Figure 4 shows the impacts of added-value by the industrial sector of other cases compared with the BaU case. The increase of electricity prices will have much effects on the energy-intensive industries (Textiles, Pulp, paper and paper products, Chemicals, Non-metallic mineral products, Basic metal, Fabricated metal products and machinery, Other manufacturing industries, Construction) .

% change from BaU

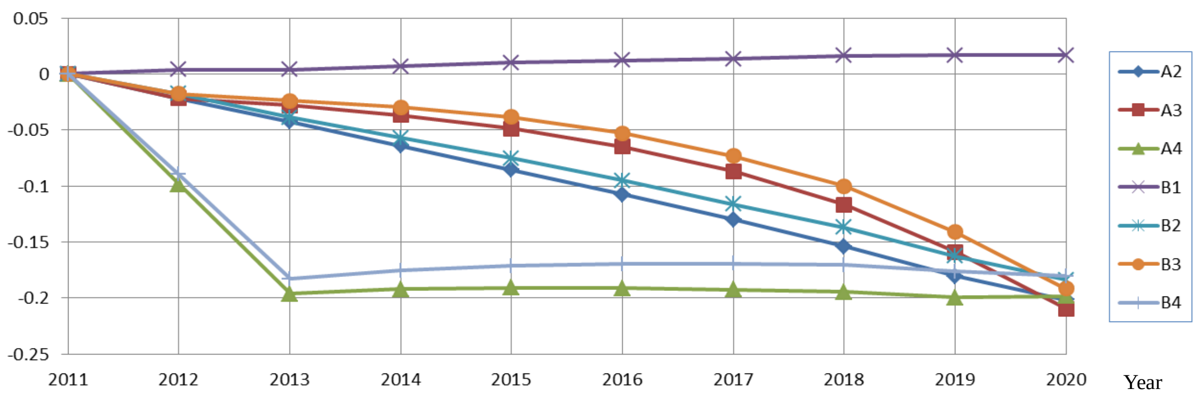

Figure 3 Change ratio of GDP of other cases compared with the BaU case (Case A2-A4 and B1-B4)

% change from BaU in 2020

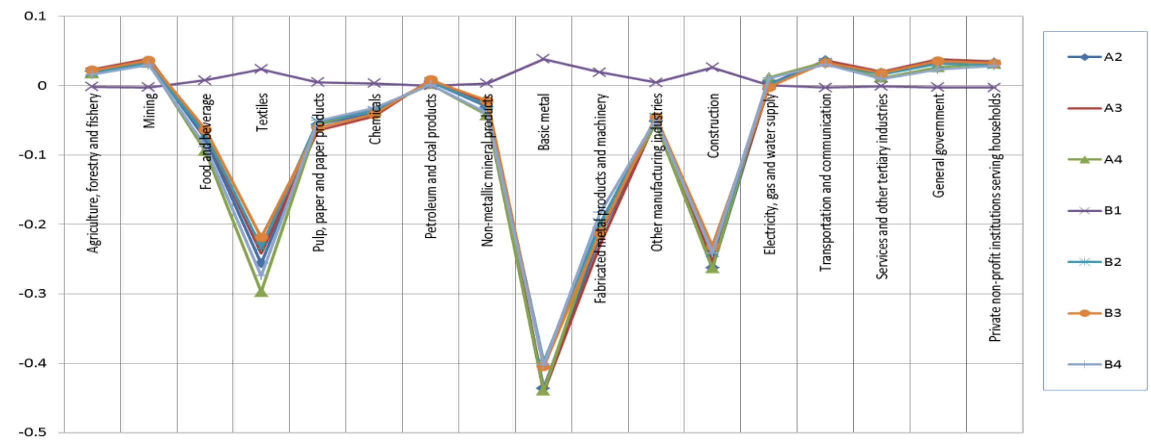

Figure 4 Impacts of the added-value by the industrial sector of other cases compared with the BaU case (Case A2-A4 and B1-B4)

4.2 Impacts on the production price by the industrial sector

Production costs by the industrial sector are estimated by energy costs and intermediate inputs etc. In the energy-intensive industries (textiles, non-metallic mineral products, basic metal, and other manufacturing industries), the increase ratio of production prices are about 1.0%, 0.3%, 2.5%, 0.5%, respectively against the BaU case in 2020 (see Figure 5). It is because of the increase of the rising electricity prices, and the increase amount of intermediate inputs.

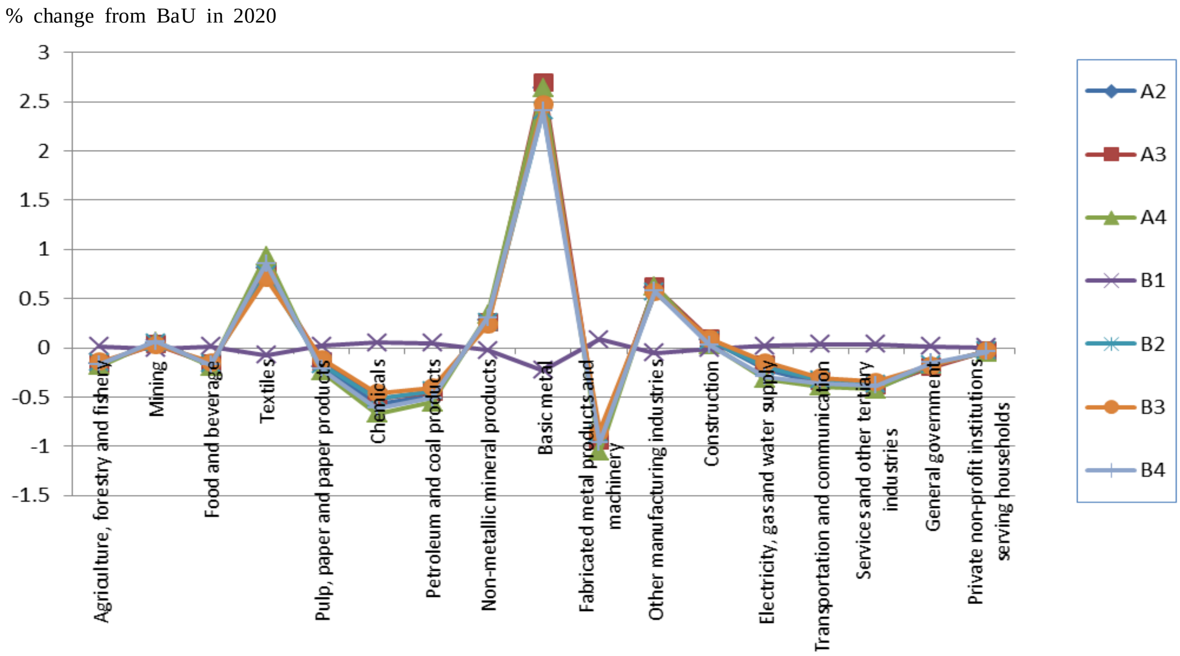

Figure 5 Impacts of the production price by the industrial sector of other cases compared with the BaU case (Case A2-A4 and B1-B4)

4.3 Impacts on the number of employees by the industrial sector

In analysis of the number of employees by the industrial sector, the total number of employees in 2020 will decrease by about 52 million people, the average of change ratio is approximately -0.6%/year in the BaU case. In 2020, A4 case against the BaU case results in the change ratio of total employees by about 0.03%. Figure 6 shows impacts on change ratio of the number of employees by the industrial sector of other cases compared with the BaU case. An increase of production of goods and services related to introducing renewable energy power will have some job creation effects on the industrial sectors in Japan; food and beverage (0.05%), pulp, paper and paper products (0.07%), basic metal (0.16%), fabricated metal products and machinery (0.14%), construction (0.11%) and so on.

% change from BaU in 2020

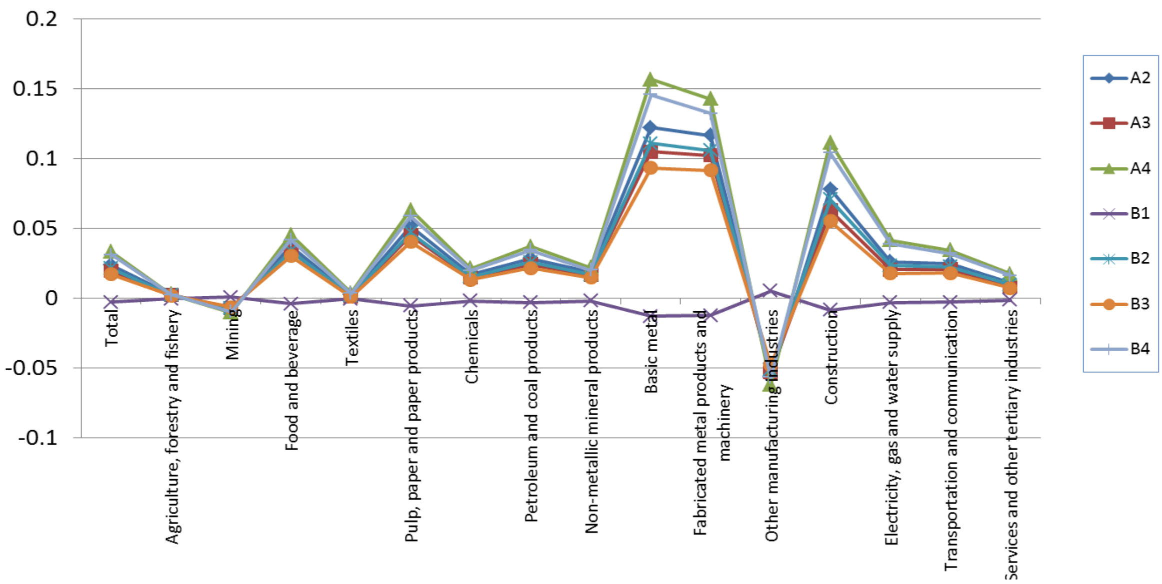

Figure 6 Change ratio of the number of employees by the industrial sector of other cases compared with the BaU case

4.4 Impacts on CO_2 emission reduction

According to our simulation results, the increasing ratio of CO_2 is approximately 0.6%/year in the BaU case, that is about 1,223 million CO_2-ton in 2020. Figure 3 shows the change ratio of CO_2 emission by other cases compared with the BaU case. By introducing renewable energy, the reduction rates of CO_2 are about -0.6 to -1.0% (in 2020). From this result, it shows that the introduction of renewable energy in A4 case has the largest impact on CO_2 emission (see Figure 7).

% change from BaU

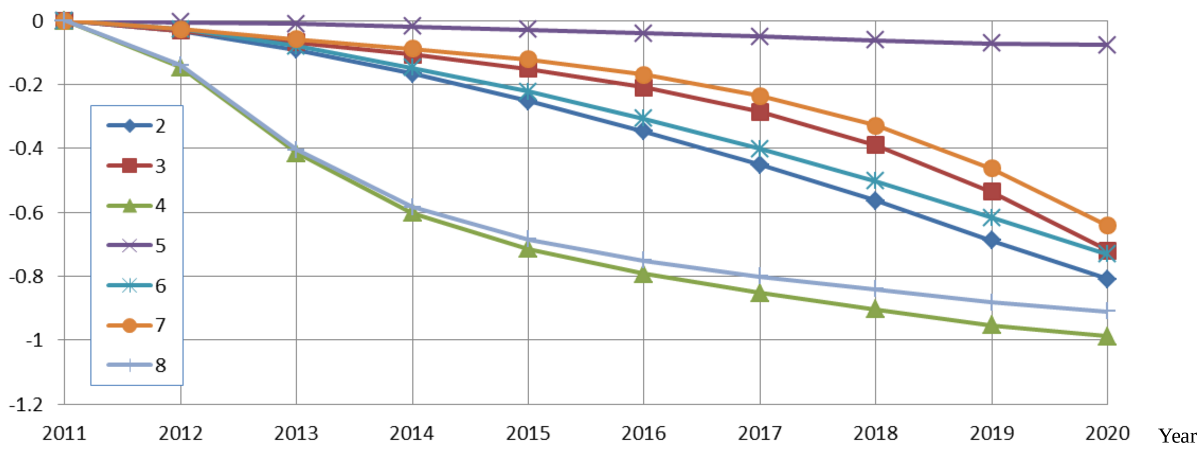

Figure 7 Change ratio of CO_2 emissions of other cases compared with the BaU case

4.5 Summary of the simulation results

We can sum up our simulation results into the four points listed below:

- Introducing of renewable energy power will raise electricity prices and production costs by the following sectors: textiles (1.0%), non-metallic mineral products (0.3%), basic metal (2.5%) and other manufacturing industries (0.5%) against those of BaU in 2020. GDP will be reduced by about 0.2% with the production cost rising, and CO_2 emission will be reduced by about 1.0%.
- Concerning results of the industrial sectors, production cost rising by introduction of renewable energy power will have some negative effects on added-value by the following industrial sectors: textiles (-0.30%), basic metal (-0.45%), construction (-0.25%) in 2020.
- By an increase of production in the industrial sectors with the introducing renewable energy, the change ratio of total number of employees will be increased by about 0.2 to 0.3% in 2020. And it will have some job creation effects on following sectors: food and beverage (0.05%), pulp, paper and paper products (0.07%), basic metal (0.16%), fabricated metal products and machinery (0.14%), construction (0.11%) and so on.
- In the case that the number of nuclear power plants in operation is fixed (B1), GDP will increase (0.02%) by electricity price decline due to the reduction of installed capacities of thermal power plants and their fuel costs.

5. CONCLUSIONS

In this study, we have developed the hybrid economy-energy econometric model, and analysed the impact of the dependency of Japan's nuclear power and renewable energy power between 2011 and 2020, with the aim of economic and energy demand-supply impacts evaluation of a variety of alternative implements for nuclear after the Tohoku-Pacific Ocean Earthquake.

Obtained results and policy implications are as follows:

Introduction of the renewable energy power will promote CO_2 emission reduction. However, with the production price increase by the electricity price increase, GDP will be reduced by about 0.2% against the case where renewable energy power is not introduced in 2020. Concerning the reduction ratio of added-value by the industrial sector, the ratios are comparatively-large in follows industry sectors: textiles (0.25%), basic metal (0.4%) and construction (0.25%). Therefore, when the renewable energy power would be installed, the government will have to take the privilege measures for such industries whose cost burdens from electricity price rising would be great. On the other hand, with the increase on production amounts by the introduction of renewable energy power, the total number of employees will increase by about 0.2 to 0.3% in 2020.

Finally, we should take notes about the issues of our study and summarize them into two points.

- We have estimated parameters of equations in this model by using annual data between 1991 and 2008. Possibility of parameters' change after the Tohoku-Pacific Ocean Earthquake is not considered. Therefore, for the improvement of reliability in the simulation results, we should have an additional study and analysis in the estimation of variables after the quake.

- In this model simulation, concerning the renewable energy power introduction, we have added the introduction amounts to the final demand of the fabricated metal products and machinery sector directly, and treated the introduction amounts as a product of the fabricated metal products and machinery sector. Therefore, for more reliable and quantitative analysis of introducing of the renewable energy (photo voltaic system and wind generator system) impacts in terms of energy demand-supply, CO_2 emission and so on, of macroeconomic and industrial sectors, we will have to construct a renewable energy sector additionally as one of the industrial sectors, and use an input coefficient based on its actual production processes.

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