An Evaluation of Policy Measures against Global Warming by Promoting Effective Use of Potential Energy in Wastes

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Abstract

Utilizing potential energy in wastes is significant for achieving sustainable development of the environment and the society. It can not only prevent the wastes from polluting the environment, but also possess many other advantages such as saving energy resources, material recycle and creation of employment. Moreover, reuse of wastes can also play an important role in mitigating global warming by reducing emission of methane, which is likely to be generated from stockbreeding wastes left in the open. The greenhouse effect of a methane molecule is 21 times higher than that of a carbon dioxide.

To promote effective use of potential energy in wastes and restructuring the existing energy system, some management instruments and economic policies need to be adopted. In this regard, levying tax on emission of greenhouse gases (GHGs) and subsiding industries producing energy from wastes are considered most applicable and effective. The aim of this study is to evaluate the economic policies in which the tax and subsidy are introduced.

For this purpose, a socioeconomic model has been constructed. The model is based on an I/O model and considers the flow of wastes and energy. New industries which produce energy from wastes, as well as the economic policies of the tax and the subsidy are introduced in the model. Being subject to restriction on total emission of GHGs, GDP is maximized as the objective function. The effects of the policies on reducing GHG emission and promoting new industries have been analyzed and the optimum tax rate is proposed.

Keywords

Model simulation, Global warming, Renewable energy, Wastes, Policy evaluation

1. Introduction

A rapid expansion of the human activity in recent years has become to face the new barrier of environmental issues with overwhelming happiness and benefit. Environmental problems are the results of the loss of global balance between the environmental burdens by human activity and processing capacities of the nature. Cyclic uses of materials need a large amount of energy though a sustainable society is required to be constructed by the cyclic uses of materials to regain the balance. Therefore, energy system is the key issue for constructing the sustainable society.

Energy consumption of the world greatly depends on the fossil fuel now and it runs counter to sustainability in two terms of resource and waste. Both of them lead to two problems of resource depletion and global warming respectively. To escape from the fossil fuel dependence, renewable energy such as the photovoltaic generation or wind power generation is necessary because energy cannot be recycled. However, it is considered to take a long time for the energies to penetrate our life. Biomass energy from waste is paid attention as a measure with the immediate effect on the energy problem. Positive energy use of carbon-neutral biomass causes a decrease in the consumption of the fossil fuel, and becomes one big step toward the sustainable society.

Moreover, considering that some wastes discharge methane gas which has 21 times global warming effect of carbon dioxide, appropriate disposal of waste may have the remarkable effectiveness on postponing global warming. Additionally, secondary effects on the cyclic use of materials and new industries are expected.

Though the potential energy of domestic biomass in waste corresponds to 5.4% of the primary energy supply according to New Energy and Industrial Technology Development Organization [11], the actual use in 1999 is about only 20% of the potential energy. The positive political measures are desirable to promote the utilization of the potential biomass energy. Because the major reason that the promotion of renewable energy isn’t in progress is in its cost, economical measures such as environmental taxes and subsidies are considered to be effective. However, it is difficult to forecast the effectiveness of these policy measures, and it takes huge cost to change the actual policy measures through a trial and error process. Model simulation is a dominant method of prior forecast and estimation of the effect of the policy. If it is used under awareness of property and limit, the cost benefit compared to introducing the actual policy will be beyond the demerit of uncertainty, though an exact modeling of a social economic system is difficult.

Edmonds and Reilly [3] can be cited as an early study simulating the relationship between energy and economy over global warming. AIM Project Team [1] in which environmental taxes and subsidies are considered and Mori [8] in which emission trading is considered are two of the long time global model evaluating the politic parameters of economy. On the other hand, Higano [4] derived the tax on environmental value added by the linear ecosystem model considering the mass balance and the value circulation. Moreover, Sakurai et al. [12] found the environment tax rate to maximize GDP under the restriction of the greenhouse gas emission based on the I/O model. Lee et al. [5] simulated the best environment tax rate concerning the promotion policy to introduce renewable energies.

As mentioned above, no examples of attention to recycling the waste which is considered to be fundamental for the recycling society have been found thus far, though there is researches which introduces the economic policy based on the I/O mode l or discusses the optimal policy for promotion of the reduction of the emission of the greenhouse gas and promotion of renewable energies. The aim of this study is to clarify the extent and the effect of a proper environment tax to maximize economic activity under the restriction of the greenhouse gas emission in Japan by the computer simulation of a socioeconomic model on the assumption of utilizing the biomass energy in wastes. And the extent of contribution of the energy utilization to reduce the greenhouse gas emission.

2. Simulation model

2.1 Outline of the model

A socioeconomic model based on I/O model was used in the simulation, in which wastes disposed by each section and energy industries using wastes as raw materials were newly considered. The production function of the Leontief type was assumed in industrial sector to consider the mass balances. In the final consumption section, however, the consumption function based on Cobb-Douglas utility function was used because it seemed that the mass balances of product did not have to be considered and it was necessary to consider the price elasticity to some degree. Therefore, the cost share of each good or service becomes constant.

Three economic agents (industry, final consumption sector and the government) were assumed in this model. Industry sector consists of energy, waste management and usual goods (including services), and the energy sector consists of existing energies and newly introduced energy industries. These energies as goods are classified into 13 kinds by the properties and the characteristics. Chosen new energy technologies are already introduced in our society or in verification test at demonstration plant which are considered to be promising. The waste treatment industry was reclassified based on the data of Ministry of Internal Affairs and Communications [6] and Nakamura [9]. All industrial classifications in each sector are shown in Table1 to 3. Exogenous data such as input coefficients were recalculated being based on the data of 2000 concerning usual and energy industries and 1995 concerning waste treatment industries.

Table 1 Classification of usual industries (Including services)

No.	Industry	No.	Industry	No.	Industry
1	Crop cultivation	10	Ceramic, stone and clay products	19	Construction
2	Livestock and agricultural services	11	Iron and steel	20	Water supply
3	Forestry	12	Non-ferrous metals	21	Sewage disposal
4	Fisheries	13	Metal products	22	Commerce
5	Metallic and non-metallic ores	14	General machinery	23	Railway transport
6	Foods	15	Electrical machinery	24	Road transport
7	Textile products	16	Transportation equipment	25	Other transport and Communication
8	Pulp, paper and wooden products	17	Precision instruments	26	Services and Public administration
9	Chemical products	18	Miscellaneous manufacturing products		

Table 2 Classification of energy and energy industries

Energy classes	Fossil Fuels	New energy
Raw material (Solid Fuels)	Coals	

Raw material (Liquid Fuels)	Crude petroleum	
Raw material (Gaseous Fuels)	Natural gas	Methane Fermentation
Raw material of dimethyl ether		Synthetic gas
Fuel for home heating equipment	Kerosene	Woody pellet
Fuel for gasoline-powered vehicle	Gasoline	Ethyl alcohol
Fuel for diesel-powered vehicle	Diesel oil	Dimethyl ether Biodiesel
Other liquid fuels	Other petroleum refinery products	
Solid fuels	Coal products	
Electricity	Nuclear power Oil-fired thermal power Coal-fired thermal power Gas-fired thermal power Water power, etc.	Waste power generation Compound Waste power generation Fuel cell
Private power generation	Private power generation	
Gaseous fuel	Gas supply	
Heat supply	Steam and hot water supply	

Table 3 Classification of waste treatment industries

No.	Wastes	No.	Wastes	No.	Wastes
1	Food waste	7	Dust, incineration ash and slag	13	Construction debris
2	Waste paper and waste textiles	8	Wood waste	14	Animal waste
3	Waste plastics	9	Organic sludge	15	Carcass
4	Metals and glasses	10	Inorganic sludge	16	Bulky waste
5	Waste rubber	11	Waste oil	17	End-of-life vehicles
6	Animal and vegetable residue	12	Waste acid and waste alkali	18	Molten slag

The object of taxation for the environment tax is the greenhouse gas emission. In concrete terms, it is assumed to be imposed on the purchaser in proportion to the amount of the carbon when fossil fuel is purchased. New energy fuels are untaxed because of their property of carbon neutral though they also emit the greenhouse gases. The tax revenue is assumed to be all devoted to the subsidy for new energy industries and waste treatment industries, as the special purpose tax. Then the apparent price of fossil fuel will move up, and we assumed that the price of new energy fuel is same as fossil fuel to be indifferent for the purchaser. Consequently, the actual price of new energy fuel can be set higher corresponding emission tax.

The substitution of the energy services is assumed to occur only in same classes when the price par energy is equal. The emission tax to fossil fuel and the subsidy for new fuel and waste treatment industries are expected to compensate the difference in cost. So the substitution to new low-emission energy is expected to advance by restriction of total amount of the greenhouse gas emission.

The waste classified into 18 is disposed corresponding to the emission coefficient from the activity of each section. The coefficients of emission which new energy industries input become negative. Inputs can't exceed total amounts of discharge though the excesses are treated in final disposal when the total amounts of emissions exceed the inputs.

The emission coefficient of the greenhouse gas is also assumed to be constant by each section and the total amount of the emission was estimated. The emission coefficient was calculated from the input coefficient of the fossil fuel to each industrial section and government. In private consumption sector, however, emission from each fossil fuel was summed up corresponding to change in their proportion. Carbon dioxide (CO_2) and methane (CH_4) were selected as the greenhouse gas because they account for 90% or more of the effect of global warming.

As other preconditions, productions of hydro-power and nuclear power in 2000 were assumed to be an upper bound in this simulation because of the problem of location of hydro-power generation and uncertainty of risks in nuclear power generation. Next, the energy consumption of the final consumption sector was assumed to be no reduction in the future, and the lower bound of the consumption of each energy class was assumed as a value in 2000. Moreover, capital was in proportion to the production because this model is static and necessary investment for production assumed to be completed. And all the investments were depreciation because no additional investment were assumed to be plowed. Finally, to clear away the possibility of an unreal change, the value of price rate was assumed to be from 0.9 to 1.1.

The objective function is GDP and solved the maximization problem of the objective function, under restriction of total amount of the greenhouse gas emission in addition to above-mentioned restriction of flow balances and the operating variable which is environment tax rate. The simulation software was LINGO of the LINDO Systems Inc.

2.2 Details of the model

2.2.1 Balance of the flow of usual goods and services

$$X_1 \geq A_{11}X_1 + A_{12}X_2 + A_{13}X_3 + A_{14}X_4 + C_1 + G_1 + Q_1\Delta K_1 + Q_2\Delta K_2 + Q_3\Delta K_3 + Q_4\Delta K_4 + Q_g\Delta K_g + E_1 - M_1 \quad (1)$$

Where

Subscript 1: Usual industries or goods (including services)

Subscript 2: Conventional energy industries (mainly fossil fuels)

Subscript 3: New energy industries (using biomass wastes as raw material)

Subscript 4: Waste treatment industries or services

Subscript e: Energy services

Subscript c: Private consumption

Subscript g: Government

X_i : Endogenous column vectors of product of each industry in sector i

A_{ij} : Exogenous matrices of input coefficients of goods i to each industry in sector j

C_i : Endogenous column vectors of private consumption of goods i

G_i : Exogenous column vectors of governmental consumption of goods i

Q_i : Exogenous matrices of input coefficients of goods for the fixed capital formation by each industry of sector i

ΔK_i : Endogenous column vectors of fixed capital formation by each industry of sector i

E_i : Exogenous column vectors of the export of goods i

M_i : Endogenous column vectors of the import of goods i

2.2.2. Balance of the energy flow

Alternative energies in the same class l (Classified in Table 2) satisfy the following relationship.

$$X_2^l + X_3^l \geq A_{e1}^l X_1 + A_{e2}^l X_2 + A_{e3}^l X_3 + A_{e4}^l X_4 + c_e^l + g_e^l + e_e^l - m_e^l \quad (2)$$

The energy-based formula of demand and supply balance is equivalent to the product-based formula by the assumption that the prices par energy of alternative fossil fuels and new energies are even. Both energies are indifferent from purchaser and only the total amount will be decided. Then the subscript for energy as service was e instead of 2 and 3.

2.2.3 Balance of the flow of wastes

$$W = A_{41} X_1 + A_{42} X_2 + A_{43} X_3 + (\ell C_1 + \ell C_e) A_{4c} + (\ell G_1 + \ell G_e) A_{4g} \tag{3}$$

Where

W : An endogenous column vector of total disposal of wastes

ℓ : A row vector for summing up

2.2.4 Total amount of emission of greenhouse gas

Emission coefficient of greenhouse gas were converted to CO_2 equivalent as greenhouse effect using data of Nansai[10]. Then they were recalculated to carbon equivalent. CO_2 emission with the final disposal of wastes is not considered in this study, but CH_4 emission from wastes were rated as worth the difference of greenhouse gas effects between CH_4 and CO_2 because CH_4 can be converted to CO_2 in new energy industries. A_{cw} is the coefficient. B_{c3} is a coefficient which is subtracted from CO_2 emission of new energy industries except electric power, corresponding to the amount of CO_2 emission with consumption of equal alternative fossil fuels.

Where

W_c : Endogenous variable of total emission of greenhouse gas

A_{ci} (i=1...4): Exogenous row vectors of greenhouse gas emission coefficients of each industry in sector i

A_{cc} : Exogenous row vectors of greenhouse gas emission coefficients by consumption of each energy class from private consumption sectors

A_{cg} : Exogenous variable of greenhouse gas emission coefficients by all consumption from government

A_{cw} : Exogenous row vectors of greenhouse gas emission coefficients from each waste

B_{c3} : Exogenous row vectors of greenhouse gas emission saved by consumption of new energies corresponding to the emission from alternative fossil fuel

2.2.5 Value balances of usual industries

$$P_1 \tilde{X}_1 \leq P_1 A_{11} \tilde{X}_1 + P_e A_{e1} \tilde{X}_1 + P_4 A_{41} \tilde{X}_1 + Y_{h1} + \delta_1 \tilde{X}_1 + \tau_1 \tilde{P}_1 \tilde{X}_1 + \tau_e \tilde{A}_{c1} \tilde{X}_1 \tag{5}$$

The left side of the formula shows the income and the right side shows the cost. Price rates P of all industries are 1 at the bench mark year 2000, and one of the industries (Crop cultivation in this study) is always fixed as 1 because the price rates are relative value. A similar relationship is assumed about the fossil fuel industries.

Where

P_i : Endogenous row vectors of price rates of goods i

Y_{hi} : Endogenous row vectors of national income of each industry in sector i

δ_i : Exogenous row vectors of depreciation of each industry in sector i

τ_i : Exogenous row vectors of indirect tax of each industry in sector i

τ_e : Exogenous value of emission tax rate, the operating variable

$\tilde{X}_1$: Diagonalized matrices

2.2.6 Value balances of new energy industries

$$\begin{aligned} P_3\tilde{X}_3 + \tau_e B_{c3} X_3 + \tau_3^s = P_1 A_{13}\tilde{X}_3 + P_e A_{e3}\tilde{X}_3 + P_4 A_{43}\tilde{X}_3 \\ + Y_{h3} + \delta_3\tilde{X}_3 + \tau_3\tilde{P}_3\tilde{X}_3 + \tau_e\tilde{A}_{c3}\tilde{X}_3 \end{aligned} \quad (6)$$

Second term of left side is corresponding to the emission tax paid to consumption of fossil fuel by the purchaser and third term is subsidy. It is similar as waste treatment industry, which can be paid the subsidy.

Where

τ_i^s (i=3,4) : Endogenous row vectors of the subsidy to each industry in sector i

2.2.7 Disposable income

The cost of waste treating is mandatory, so it is subtracted from disposable income similar to the direct tax.

Where

Y_d : Endogenous value

τ^d : Exogenous value of direct tax rate

${}^tY$: Transposed vector of Y (row vector to column vector, vice versa)

2.2.8 Consumptions of the private consumption sector

$$P_1\tilde{C}_1 = (1-\beta)Y_d\alpha_1 \quad (8)$$

$$P_2\tilde{C}_e + \tau_e A_{cc}\tilde{C}_e = (1-\beta)Y_d\alpha_e \quad (9)$$

$$\ell^t\alpha_1 + \ell^t\alpha_e = 1 \quad (10)$$

The share of cost with each good or service of disposable incomes is constant. As energy services, the emission tax concerning the consumption is added to the expense (left side of (9)). A fraction of the disposable income is saved, but all the rest is disbursed for consumption (formula (10)).

Where

α_i : Exogenous row vectors of cost share with goods i in private consumption sector

β : Exogenous value of saving ratio to income

Some other constraints are omitted such as the balance of the government in which the income from the emission tax and the expenditure of the subsidy are same, the saving and investment balance of the government in which the saving is set aside to the net export (net foreign investment) because no new investments are assumed, and the constraint that the fixed capital formation only consists of depreciation, etc.

2.2.9 The objective function (GDP)

$$\begin{aligned} GDP = Y_d + \delta_1 X_1 + \delta_2 X_2 + \delta_3 X_3 + \delta_4 X_4 \\ + \tau_1^i \tilde{P}_1 X_1 + \tau_2^i \tilde{P}_2 X_2 + \tau_3^i \tilde{P}_3 X_3 + \tau_4^i P_4 W \end{aligned} \qquad (11)$$

The optimal level of the socioeconomic activity to satisfy given level of environment is obtained by solving the maximization problem of GDP at given restriction of CO_2 emission.

2.3 Estimation method of certain coefficients

Though some classes of industrial sector in this study are more particular than I/O table, roughly classified data is used as their coefficients per product. The value of production in the thermal power generation is divided in proportion to the data of the electricity generated from oil, coal and natural gas respectively. Their input coefficients is estimated assuming that oil, coal and natural gas are input only to respective industries of power generation and other input ratios of raw materials are the same.

Exogenous coefficients of new energy industries are estimated using the data of demonstration plants. Though their prices necessary to calculate the coefficients are unknown, they are estimated assuming that their prices per energy equals to that of alternative fossil fuels. Coefficients of new industry at bench mark year are assumed to be 0.

3. The results and the discussion

3.1 The relationship between the restriction of emission and GDP

The greenhouse gas emission restriction dependency of GDP without emission tax and subsidy is shown in Fig.1 in the case with and without introducing the waste-utilizing new energy industries. When the restriction was from the actual data of 2000, GDP was 560 trillion yen (4.15 trillion euro, 1 euro=135 yen) in both cases of with and without new energy industries. It was more biggish than 511 trillion yen (3.79 trillion euro), the actual value of 2000 according to Economic and Social Research Institute, Cabinet Office, Government of Japan [2]. When the emission restriction was tightened up less than 95% of 2000 without new industries, a rapid decrease of GDP was shown, and no solution was obtained less than 87%. On the other hand, the decrease of GDP was gradual with new industries and solution was obtained down to 82%.

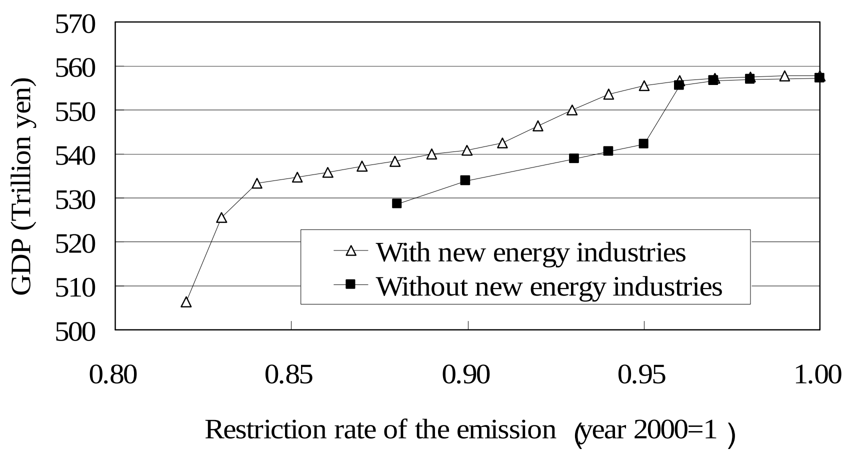

Fig.1 Greenhouse gas emission restriction dependency of GDP

Japanese goal of Kyoto Protocol was calculated as 317 million tC and 87% of actual emission of 2000 according to Ministry of the Environment [7]. When the restriction is set to this value, GDP was 5.11 trillion dollars with new industries and was 3.7% decrease from data of 2000. No solution was obtained at that restriction without new industries. As mentioned above, introduction of new energy industries was shown to have effect of making GDP increase when the restriction of greenhouse gas emission was severe.

To examine the factor of rapid decrease in GDP at the restriction less than 95% of 2000 without new industries, changes of production were checked by each industry. As the restriction gets strict, productions of energy industries were observed to decrease more than usual industries, and particularly the production of heat supply became nearly zero at 96% restriction. Restriction of emission was satisfied by the decrease of heat supply at first, and after no option of decreasing was left at 95% restriction, other energy industries began to decrease their productions. From here onwards, rapid shrinking of whole industries is considered to start to satisfy the restriction at 95%. It is remarkable that organic mud emitting CH_4 increases rapidly from 96% restriction to 95%. It is caused by decrease of production of Crop cultivation which inputs organic mud (some industries other than new energy input wastes). The shrinking of whole industry is considered to be necessary to satisfy the restriction, to cover the increase of CH_4 corresponding to organic mud.

Productions of new energy industries when they were introduced were shown in Fig.2. Methane fermentation and woody pellet showed constant productions regardless of the restriction. Biodiesel were produced at more strict restriction, and dimethyl ether through synthetic gas was produced at still more strict restriction. The total value of production of new energy industries was up to 315 billion yen (2.34 billion euro) and 273PJ in energy. It corresponds to be 1.7% of final energy consumption in Japan.

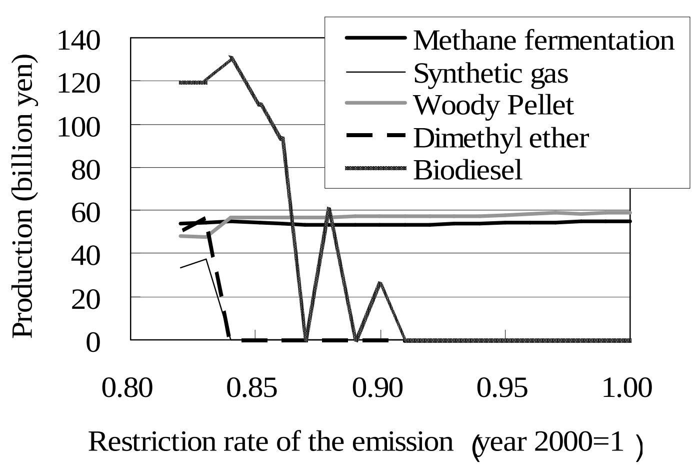

Fig.2 Production of new energy industries under the restriction of greenhouse gas emission

Biodiesel was produced at strict restriction though there observed discontinuity. As for other industries, no remarkable changes were shown in the usual industries and energy industries decreased their production corresponding to the restriction. Fossil fuels such as gasoline, kerosene and diesel oil input waste oil which is the raw material of biodiesel, and the reason of production in biodiesel is considered that waste oil could be input to the industry with the reduction of production in those fossil fuel industries.

Productions of new energy industries which input the urban garbage such as paper, fiber and plastic hardly occurred at all though the raw material of methane fermentation is the animal waste and organic mud, and that of woody pellet is wood waste. The urban garbage utilizing industries also input wood waste and kitchen waste, but almost all of them were used for methane fermentation or woody pellet and it caused that result. Since some substitutability is observed between wastes like wood waste and urban garbage about the input of waste, there is a possibility to utilize more wastes by modification of the simulation model considering the substitutability.

3.2 Influence of introducing the emission tax and subsidy

Next, the simulation was conducted introducing the emission tax and subsidy. The restriction was set as the actual value of 2000 and the target of Kyoto Protocol, with new energy industries. The change in GDP is shown in Fig.3. In both cases GDP increased corresponding to the tax rate and the effects were 4.3 trillion yen (31.9 billion euro) in 2000 restriction and 7.8 trillion yen (57.8 billion euro) in Kyoto protocol restriction, at tax rate of 4,000 yen (30 euro) per ton-carbon. But no solution was obtained at higher rates.

Figure 4 and 5 show the values of production in new energy industries at this time. The methane fermentation didn't have large tax rate dependencies with the restriction of 2000, and the woody pellet had been substituted by the ethyl alcohol in the higher tax rate area. With the restriction of Kyoto Protocol, there is no change in the kind of industry and the production of biodiesel had increased. It is considered that this substitution is not due to a large-scale change in the industrial structure because raw materials of the woody pellet and the ethyl alcohol are wood waste in common and there is no remarkable change in other industries.

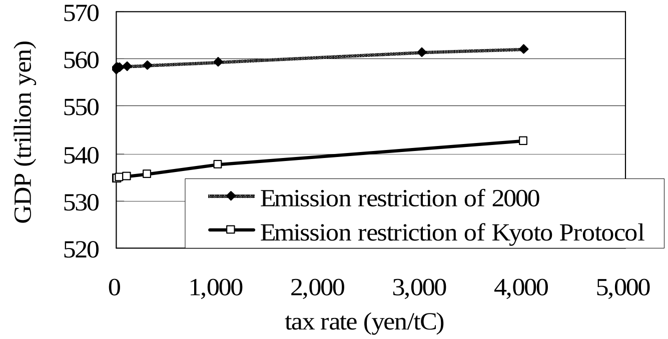

Fig.3 GDP changes when the emission tax and the subsidy are introduced

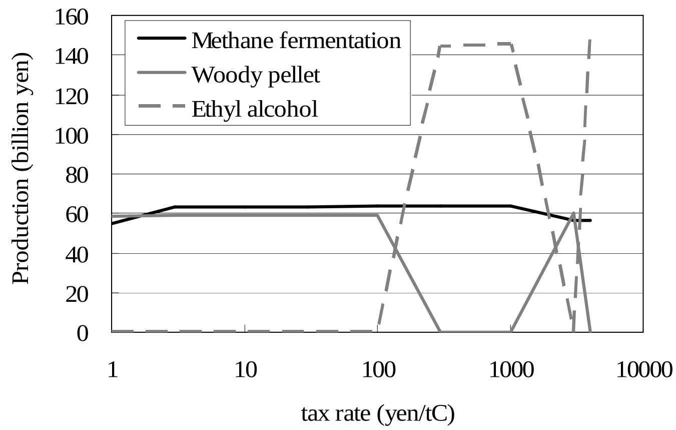

Fig.4 The relation between the emission tax and the productions of new energy industries at the emission restriction of 2000

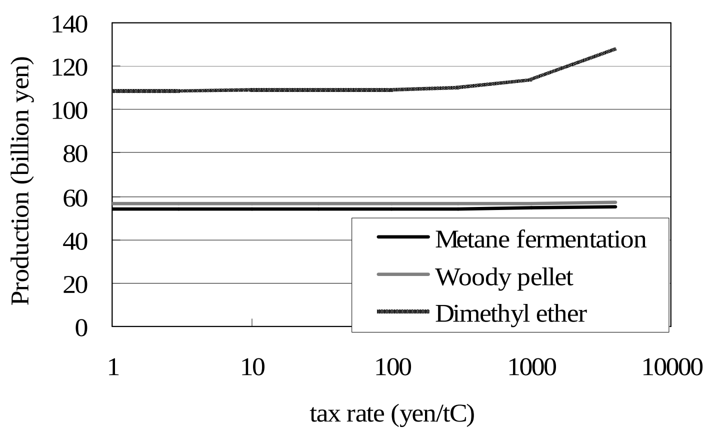

Fig.5 The relation between the emission tax and the productions of new energy industries at the emission restriction of Kyoto Protocol

Production of new industries was expected to increase corresponding to the tax rate because new energy industries have less effect on the environment and have an advantage with the introduction of emission tax. However, some new energy was produced in the simulation without emission tax and the increase of production was not prominent even though the tax rate rose. One of the reasons is contemplated that the process of investment is not represented in the simulation model because the model is static and the investment needed for production is treated to have been completed. It was distinguishing that the production of methane fermentation which doesn't have advantage at cost-effectiveness was occurred constantly. It suggest that the methane fermentation industry has an economic advantage under the emission restriction since the industry which treats methane gas from wastes adequately has large effectiveness for reducing greenhouse gas emission.

Few industries decreased the production at the tax rate of 4,000 yen (30 euro) per ton-carbon compared to no taxation. They are the heat supply (0.068 times without taxation), the city gas (0.91 times) etc. at the restriction of 2000, and the kerosene (0.013 times), the crude oil (0.75 times) etc. at the restriction of Kyoto Protocol. All of these are energy industries and the emission quotas of greenhouse gas for other industries with less emission coefficients was expanded by the shrinking of the production of the industries that contribute to the total emission of greenhouse gas directly. It is considered to be the cause of the GDP increase.

To examine the mechanism of above changes by introducing the tax and the subsidy, the subsidy allocation was studied. It became apparent that the subsidy was allocated not only for new energy industries such as methane fermentation but for the waste treating industries including the disposal of metal and glass which don't generate energy. This proves that expanding of economy also occurs by the distribution of subsidy for waste treating industry generating no energies under the emission tax.

Finally, the effect of the introduction of the tax and subsidy on GDP was converted to the effect on the capability of reducing greenhouse gas emission. The result is shown in Fig.6. It indicates that the same GDP can be established by the emission tax to the rate shown as the transverse value on the figure, when the restriction of the emission is reduced by the vertical value. From both of the cases calculated on the bases of the restriction of 2000 and Kyoto Protocol, it is shown that the emission tax of 4,000 yen per ton-carbon corresponds to the reduction on greenhouse gas emission by about 6% on the effectiveness.

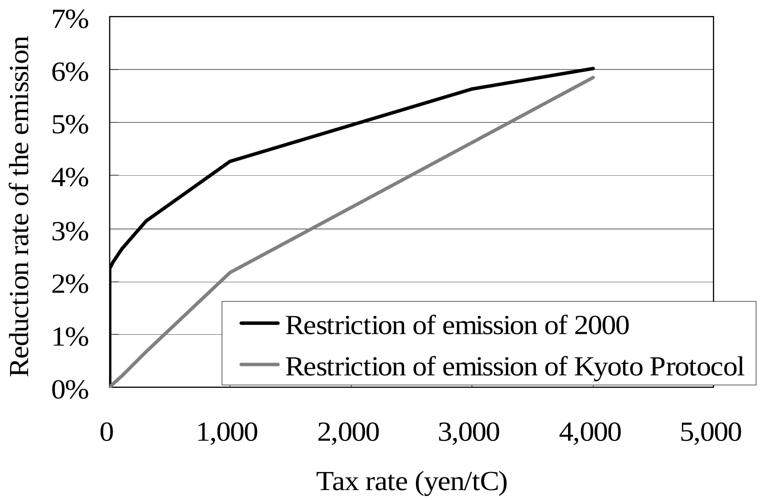

Fig.6 Converted effect of the emission tax for the reduction of greenhouse gas emission

4 Conclusions

In this study, promotion of new energy industry was aimed which utilizes the energy in biomass waste and can be introduced at the early stage, and simulated the maximization problem of economic activity under the restriction of greenhouse gas emission by a socioeconomic model, then the following findings were obtained.

1) GDP decreased as the emission restriction of greenhouse gases became severe in both cases with and without introducing new energy industries. But the tendency to decrease was more gradual in the case with new energy industries.

2) In the case with new energy industries and without tax and subsidy, the industries of methane fermentation and woody pellets were occurred regardless of the restriction, and the production of biodiesel occurred in place of the fossil fuel industry inputting wasted oil when the emission restriction became severer, and in addition, dimethyl ethers were produced through the synthesis gas. The total value of production of these new energy became 315.5 billion yen (2.34 billion Euro) and 273PJ in the energy.

3) In the case with new energy industries, tax and subsidy, an increase of GDP was seen with the tax rate up to 4,000 yen (30 Euro) per ton-carbon, but the solution was not obtained at higher tax rate. Industries such as the methane fermentation, woody pellet,

ethyl alcohols, and biodiesel produced in a new energy industry, and a big change according to the tax rate was not seen. The shift from fossil fuel energy industry to usual industry occurred by subsidy to some new energy industries and waste treating industries and GDP increased satisfying the restriction of greenhouse gas emission.

As mentioned above, it was confirmed that the utilization of biomass energies in wastes contributes to reduce the emission of greenhouse gases and to increase GDP, and that the introduction of emission tax and subsidy is effective for it.

Finally, the modification of the simulation model to the dynamic model and the introduction of other renewable energies such as the solar power generation or the wind power generation to the model are major challenges in our researches in the future.

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