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Simulation Analysis of Policy for Waste Treatment toward a Sound Material-cycle Society in Tokyo

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Abstract

Enhancing resource productivity is effective to improve trade-off between the environment and economy. For minimizing consumption of natural resources required for economic activities, it is necessary to strengthen both material recycling and energy utilization, which reduce final disposal amount and return waste to economic activities as resource.

This study seeks to clarify environmental economic policy for promoting establishment of sound material-cycle society subject to keeping or expanding the regional economic scale, and enhancing the amount of material recycling and reducing greenhouse gas (GHG) emissions. Study area is Tokyo metropolitan area. To reduce GHG emissions and final disposal amount, we consider promoting both material recycling and energy utilization thoroughly. Under these circumstances, we construct an expanded input-output model. The model includes the flows of waste and energy, and emissions of GHG. With restrictions on GHG emissions, Gross Regional Product (GRP) is maximized as the objective function. We quantitatively analyze how much tax and subsidy on discharging waste is required for sound material-cycle society along with analysis on effects of the policy by model simulation.

The results show that, with 10 yen/kg tax on discharging waste, final disposal amount per GRP was 11% lower than the baseline case.

Keywords: energy utilization, input-output model, material recycling, policy evaluation, waste

1. Introduction

In the 1960s, during so-called high-growth period, economic activities in Japan were based on mass-production, mass-consumption and mass-disposal. This social structure initiated many environmental issues such as depletion of natural resources, shortage of landfill site and excessive emission of pollutants including GHG along with outbreak of four major environmental pollutions in Japanese history. The fundamental problem with this society is existence of trade-off between the environment and economic growth. To improve the trade-off and shift the society with a sustainable economic system, it is effective to enhance resource productivity with the idea of a sound material-cycle society.

In Japan, legal systems to establish a sound material-cycle society has already implemented around 2000 (Bureau of Environment, 2014). However, in Tokyo, majority of waste is simply incinerated and the ash goes to landfill site (Bureau of Environment, 2014). When we consider only biomass in waste, potential energy corresponds to 14.1% of the energy consumption in Tokyo whereas the actual use in 2011 is only about 5.2% of the potential energy per our estimation (see Figure 1 and Table 1). Moreover, biomass is mostly used for generating power through incineration. There are more efficient methods for biomass such as methane fermentation and conversion into biodiesel fuel (BDF). If we use these methods, we can achieve higher resource productivity.

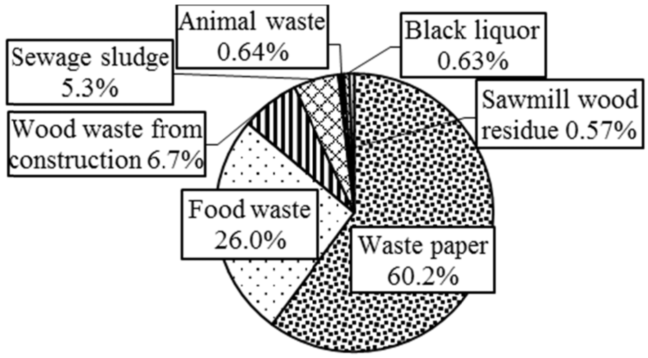

Figure 1. Composition of biomass generated in Tokyo in 2010

Table 1. Potential of utilizing biomass to energy and current situation in Tokyo in 2010

Type of biomass	Potential of biomass to energy (TJ)	Methods used for biomass to energy and its conversion amount (TJ)
Animal waste	297.5	
Sewage sludge	3593.3	Carbonization 72, Methane fermentation 84
Black liquor	635.7	
Waste paper	41 626.9	
Food waste	38 696.3	Methane fermentation 28, Conversion into BDF 418
Sawmill wood residue	779.0	
Wood waste from construction	9302.0	
Total	94930.7	3067 (Including waste power generation 2465)

Besides, after the Great East Japan Earthquake in 2011, GHG emissions per amount of energy consumption is getting higher. Figure 2 shows changes in GHG emissions and energy consumption in Tokyo (Bureau of environment, 2015). The trends show opposite directions since 2011. Tokyo Metropolitan Government has set a GHG reduction target to reduce Tokyo's GHG emissions by 25% below 2000 levels by 2020 (Bureau of environment, 2015). According to the latest data published by bureau of environment, the GHG emissions amount was 70.1 million t-CO_2eq in 2013 (Bureau of environment, 2015). This data reveals that we need to reduce 33.9% from 2013 level to meet the target. It is necessary to reconsider types of energy and change into low GHG emissions technologies to fulfill GHG reduction target.

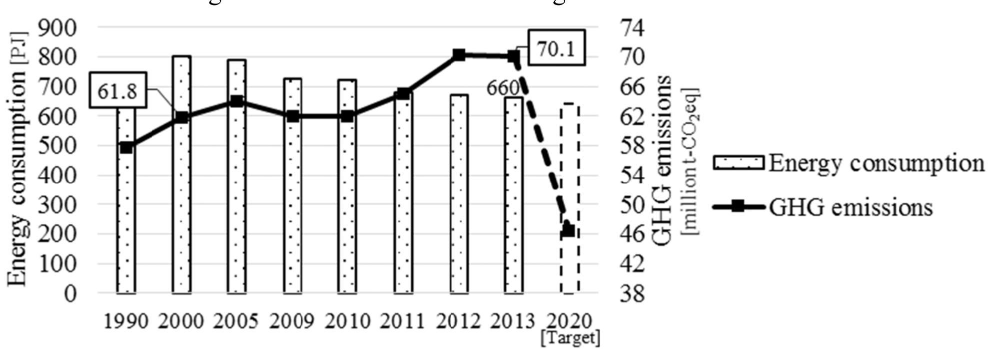

Figure 2. GHG emissions and energy consumption in Tokyo

There are numbers of research related to environmental economic policy. Iwata and Shimada (2008) constructed a model to quantify various effect of livestock manure and discussed cost-effectiveness. Chang and Lin (1998) conducted input-output structural decomposition analysis to examine industrial CO_2 emission structure. Higano

(1996) discussed distribution of value added to environmental goods focusing on value added tax derived by using the linear ecosystem model which considers value flow and material flow. Using model based on material balance, Uchida and Higano (2006) and Mitsuhashi and Higano (2005) analyzed environmental and economic effects of introducing energy utilization from waste biomass as an industrial sector. Li, Zou, Xu, Yabar, and Higano (2012) focused on E-waste and found the optimal allocation of cost between producers and consumers of electronic products by minimizing CO_2 emission.

Although some research have been done on either material recycling or energy utilization, there are very few research considering both. However, with recycling more waste thorough using various ways, we can bring waste back as resource for economic activities and reduce final disposal amount. From this point of view, we consider promoting both material recycling and energy utilization, and clarify optimal situation for waste recycling system in this study. The purpose of this study is to clarify environmental economic policy for promoting establishment of sound material-cycle society with economic and environmental preconditions, namely keeping or expanding the regional economic scale and reducing GHG emissions amount.

2. Method of Study

This study constructs a socioeconomic model based on interregional input-output table which includes import and export from both other regions in Japan and abroad. We set two new waste treatment sectors consist of material recycling and energy utilization as new industries. The model includes flows of waste and energy, and emission of GHG. We expand this model into linear programming problem, and conduct computer simulation analysis. Activities of new industries are motivated by subsidy from tax levied on amount of waste discharged from both industries and households. With restriction on emissions of GHG, GRP is maximized as the objective function. Making the emission standards strict step by step, we quantitatively analyze how much tax and subsidy on discharging waste is required for sound material-cycle society thoroughly.

The model consists of three economic agents: industry, households and the government, as shown in Figure 3 and Figure 4. Industry sector consists of 9 industries, and each industries are subdivided into smaller sections. We set 97 sections in total, which are Usual industries in Tokyo with 24 sections and in other region with 28 sections, Energy industries in Tokyo and in other region with 12 sections respectively, Waste treatment industries in Tokyo and in other region with 2 sections respectively, New waste treatment industries in Tokyo (material recycling) with 4 sections, New waste treatment industries in Tokyo (energy utilization) with 9 sections, and Material recycled goods utilizing industries in Tokyo with 4 sections. Material recycled by New waste treatment industries in Tokyo (material recycling) goes to Material recycled goods utilizing industries. Therefore these industries have same sections, which are glass, paper, plastics and metal section. The model is applied to Japanese economy as of 2011. We consider 6 types of GHG, namely CO_2, CH_4, N_2O, HFCs, PFCs and SF_6.

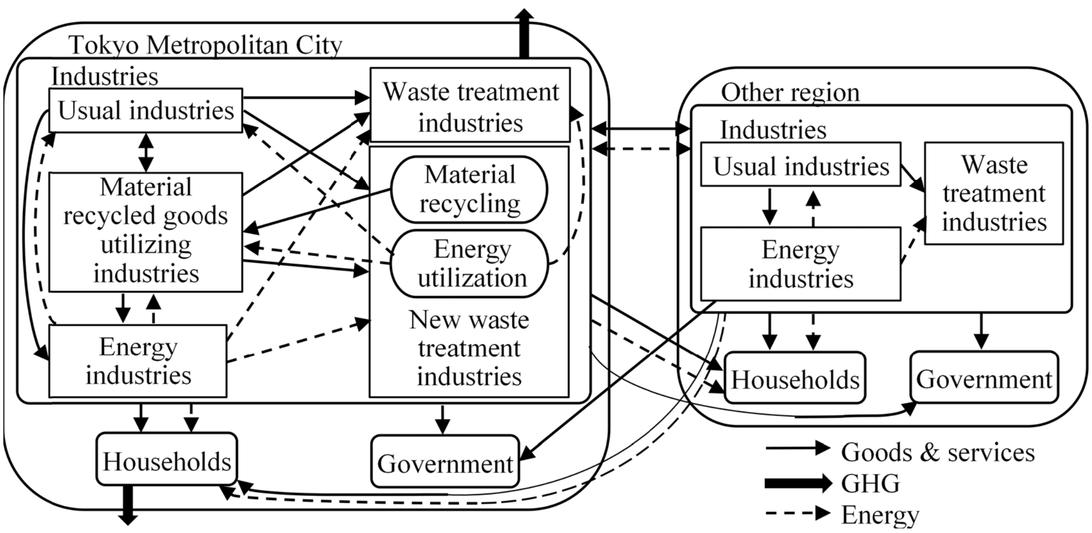

Figure 3. Flow chart of goods & services, GHG, and energy

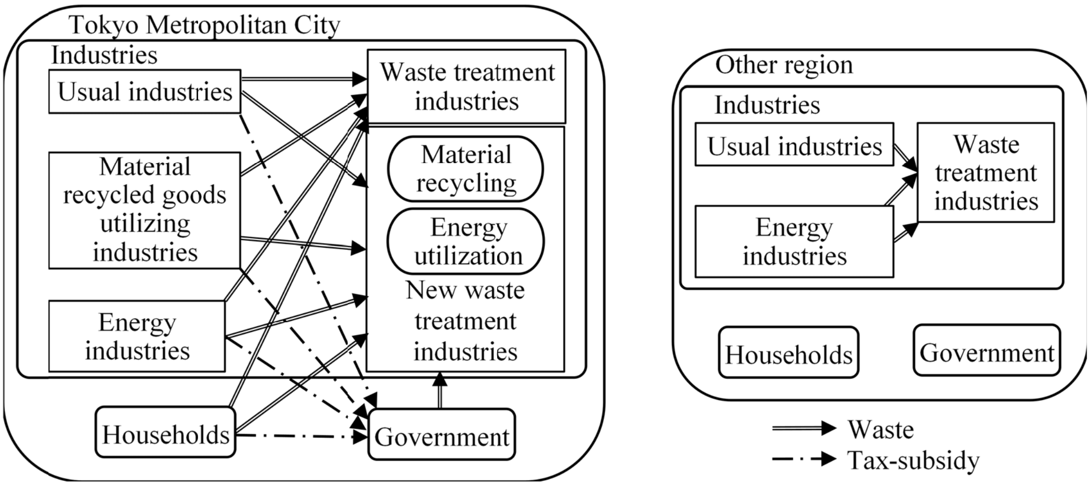

Figure 4. Flow chart of waste and tax-subsidy

We conduct this simulation with linear programming software LINGO of the LINDO Systems Inc.

Only essential model equations are presented in this paper as the model which we constructed in the study is composed of 88 equations and all of them cannot be included.

2.1 Material Balance of Usual Goods

The left side represents supply of goods, and the right side represents demand for goods. This equation describes demand-supply balance for each goods. Every usual goods industry supply more than their total demand.

$$X_i \geq A_{i1}X_1 + A_{i2}X_2 + A_{i3}X_3 + A_{i4}X_4 + A_{i5}X_5 + A_{i6}X_6 + A_{i7}X_7 + A_{i8}X_8 + A_{i9}X_9$$
$$+C_i^T + G_i^T + I_i^T + E_i^T - M_i^T + C_i^R + G_i^R + I_i^R + E_i^R - M_i^R \quad (1)$$

where

subscript i =1,7 j =1,2,3,4,5,6,7,8,9

1: Usual industries in Tokyo, 2: Energy industries in Tokyo, 3: Waste treatment industries in Tokyo, 4: New waste treatment industries in Tokyo (material recycling), 5: New waste treatment industries in Tokyo (energy utilization), 6: Material recycled goods utilizing industries in Tokyo, 7: Usual industries in other region, 8: Energy industries in other region, 9: Waste treatment industries in other region, g: Government

superscript T: Tokyo metropolitan city, R: Other region

X_j: Endogenous column vectors of production of each industry in sector *j*

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

C_i: Endogenous column vectors of households' consumption of goods *i*

G_i: Endogenous column vectors of government's consumption of goods *i*

I_i: Endogenous column vectors of gross investment demand of goods *i*

E_i: Endogenous column vectors of export of goods *i*

M_i: Endogenous column vectors of import of goods *i*

2.2 Balance of Material Recycled Goods Flow

The first entity of left side represents supply of goods which have treated at New waste treatment industries in Tokyo (material recycling). The right side represents demand for goods.

$$X_4 + X_6 \geq A_{61}X_1 + A_{62}X_2 + A_{63}X_3 + A_{64}X_4 + A_{65}X_5 + A_{66}X_6 + A_{67}X_7 + A_{68}X_8 + A_{69}X_9$$
$$+C_6^T + G_6^T + I_6^T + E_6^T - M_6^T + C_6^R + G_6^R + I_6^R + E_6^R - M_6^R \quad (2)$$

2.3 Balance of Energy Flow

2.3.1 Total Energy Demand

$$CE_j = \widetilde{X}_j\theta_j \quad (3)$$

$$CC_e = C_e\gamma \tag{4}$$

where

CE_j: Endogenous column vectors of energy demand amount of j industries

θ_j: Exogenous column vectors of energy demand coefficients of j industries

CC_e: Endogenous values of total energy demand of households

C_e: Endogenous values of households' consumption of each energy

γ: An exogenous value of energy demand coefficients of households

$\widetilde{X_j}$: Diagonal matrices whose diagonal elements are the elements of X_j

subscript e=2,8

2.3.2 Demand of Each Energy

This equation holds for both 'Tokyo metropolitan city' and 'Other region'.

$$CE_j = \sum CO_{ej} + \sum PR_{ej} + \sum NG_{ej} + \sum GL_{ej} + \sum KS_{ej} + \sum DO_{ej} + \sum OP_{ej} + \sum CP_{ej} + \sum CMP_{ej} + \sum AP_{ej} + \sum UG_{ej} + \sum RHS_{ej} \tag{5}$$

$$CC_e = P_e(1)CO_{ec} + P_e(2)PR_{ec} + P_e(3)NG_{ec} + P_e(4)GL_{ec} + P_e(5)KS_{ec} + P_e(6)DO_{ec} + P_e(7)OP_{ec} + P_e(8)CP_{ec} + P_e(9)CMP_{ec} + P_e(10)AP_{ec} + P_e(11)UG_{ec} + P_e(12)RHS_{ec} \tag{6}$$

where

CO_{2j}, PR_{2j}, NG_{2j}, GL_{2j}, KS_{2j}, DO_{2j}, OP_{2j}, CP_{2j}, CMP_{2j}, AP_{2j}, UG_{2j}, RHS_{2j}, CO_{8j}, PR_{8j}, NG_{8j}, GL_{8j}, KS_{8j}, DO_{8j}, OP_{8j}, CP_{8j}, CMP_{8j}, AP_{8j}, UG_{8j}, RHS_{8j}

: Endogenous column vectors of energy demand for each energy by each industry in sector j

CO: Coal mining, PR: Crude petroleum, NG: Natural gas, GL: Gasoline,

KS: Kerosene, DO: Diesel oil, OP: Miscellaneous petroleum refinery products,

CP: Coal products, CMP: Electricity, AP: Private power generation, UG: Gas supply,

RHS: Steam and hot water supply

CO_{ec}, PR_{ec}, NG_{ec}, GL_{ec}, KS_{ec}, DO_{ec}, OP_{ec}, CP_{ec}, CMP_{ec}, AP_{ec}, UG_{ec}, RHS_{ec}

: Endogenous values of energy demand for each energy by households

subscript c: Households

2.3.3 Total Energy Supply

Equation (7) represents that coal mining sector supply more than their total demand. Similar equations hold for each energy. For energy in 'Other region', left sides are all singular.

$$k_2(1)X_2(1) + k_5(1)X_5(1) \geq \sum lCO_{2j} + CO^T_{2c} + CO^R_{2c} \tag{7}$$

where

k_i: Exogenous row vectors of energy supply coefficient of i industries

l: A row vector for summation

2.4 Balance of Waste Flow

The total waste discharged amount consists of discharged waste by production of each industry and by household consumption. Similar equation holds for 'Other region'.

$$W^T = A_{w1}X_1 + A_{w2}X_2 + A_{w5}X_5 + A_{w6}X_6 + (lC^T_1 + lC^T_2 + lC^T_6 + lC^T_7 + lC^T_8)A_{wc} \tag{8}$$

where

subscript w: Waste

W: Endogenous column vectors of total disposal amount of waste

2.5 Amount of Emission of GHG

The amount of GHG emitted is calculated by multiplying GHG emission coefficient to products of each industry and household's consumption amount respectively.

$$GHG^T = A_{z1}X_1 + A_{z2}X_2 + A_{z3}X_3 + A_{z4}X_4 + A_{z5}X_5 + A_{z6}X_6 + A_{zc}(C_2^T + C_8^T) \tag{9}$$

where

subscript z: Greenhouse gas

GHG: An endogenous variable of total emission of GHG

2.6 Value Balances

2.6.1 Value Balances of Usual Industries

The left side represents income due to selling goods, and the right side represents expenditure needed for production. As we assume perfect competitive market, income should not exceed expenditure because firms produce until there is no excess profit. The last entity in right side represents waste discharging tax imposed on industries in Tokyo by multiplying the amount of waste discharged by production of goods and waste discharging tax rate.

$$\begin{aligned} P_1\widetilde{X_1} \le\ & P_1A_{11}\widetilde{X_1} + PCE_{21} + P_3A_{31}\widetilde{X_1} + P_6A_{61}\widetilde{X_1} + P_7A_{71}\widetilde{X_1} + PCE_{81} + P_9A_{91}\widetilde{X_1} + v_1\widetilde{X_1} + \delta_1\widetilde{X_1} \\ & + \tau_1\widetilde{P_1}\widetilde{X_1} + \tau_w{}^{t}X_1A_{w1} \end{aligned} \tag{10}$$

where

v_j: Exogenous row vectors of households' income of each industry in j industries

δ_j: Exogenous row vectors of depreciation of each industry in j industries

τ_j: Exogenous row vectors of indirect tax of each industry in j industries

τ_w: An exogenous value of tax rate on discharging waste, operating variable

Similar equations hold for 'Material recycled goods utilizing industries in Tokyo', 'Usual industries in other region', energy industries and waste treatment industries.

Expenditure on energy needed for production is equivalent to purchase of demanded amount which is determined by balance of energy mentioned above. Hence, instead of input-output coefficient, equation (11) is used for expenditure on energy which is in right side of value balance of each industry.

$$\begin{aligned} PCE_{ej} =\ & P_e(1)^{t}CO_{ej} + P_e(2)^{t}PR_{ej} + P_e(3)^{t}NG_{ej} + P_e(4)^{t}GL_{ej} + P_e(5)^{t}KS_{ej} + P_e(6)^{t}DO_{ej} \\ & + P_e(7)^{t}OP_{ej} + P_e(8)^{t}CP_{ej} + P_e(9)^{t}CMP_{ej} + P_e(10)^{t}AP_{ej} + P_e(11)^{t}TG_{ej} + P_e(12)^{t}RHS_{ej} \end{aligned} \tag{11}$$

where

PCE_{ej}: Endogenous row vectors of expenses for energy required for production of j industries

P_e: Endogenous row vectors of price rates of goods i

2.6.2 Value Balances of New Waste Treatment Industries in Tokyo (material recycling)

The last entity in left side represents subsidy for introducing new waste treatment industries and extending their activities. The subsidy comes from waste discharging tax which is the last entity of equation (10). Similar equation holds for 'New Waste Treatment Industries in Tokyo (energy utilization)'.

$$P_4\widetilde{X_4} + \tau_4^s = P_1A_{14}\widetilde{X_4} + PCE_{24} + P_6A_{64}\widetilde{X_4} + P_7A_{74}\widetilde{X_4} + PCE_{84} + v_4\widetilde{X_4} + \delta_4\widetilde{X_4} + \tau_4\widetilde{P_4}\widetilde{X_4} \tag{12}$$

where

τ_j^s: Endogenous row vectors of subsidy for industries

2.7 Disposal Income

Disposal income of household is given by national income minus direct tax. Similar equation holds for 'Other region'.

$$Y_d^T = (1 - \tau^d)(v_1X_1 + v_2X_2 + v_3X_3 + v_4X_4 + v_5X_5 + v_6X_6) \tag{13}$$

where

Y_d: Endogenous values of disposal income of households

τ^d: An exogenous value of direct tax rate

2.8 Consumption and Saving of Households

Disposal income Y_d is divided into consumption and savings of every goods by certain proportion. The sum of proportion of consumption and saving is 1. Similar equations hold for 'Other region'.

$$P_i\widetilde{C_i^T} + \tau_w{}^{t}A_{wc}\widetilde{C_i^T} = Y_d^T\alpha_i^T \tag{14}$$

$$S^{pT} = \beta^T Y_d^T \tag{15}$$

$$l\alpha_i^T + \beta^T = 1 \tag{16}$$

where

α_i: Exogenous row vectors of consumption ratio with goods i of households

β: Exogenous values of saving ratio of households

S^p: Endogenous values of saving of households

2.9 Objective Function

We set GRP as objective function and maximized it under constraints of 87 equations.

$$GRP = v_1X_1 + v_2X_2 + v_3X_3 + v_4X_4 + v_5X_5 + v_6X_6 + \delta_1X_1 + \delta_2X_2 + \delta_3X_3 + \delta_4X_4 + \delta_5X_5$$
$$+\delta_6X_6 + \tau_1\widetilde{P_1}X_1 + \tau_2\widetilde{P_2}X_2 + \tau_3\widetilde{P_3}X_3 + \tau_4\widetilde{P_4}X_4 + \tau_5\widetilde{P_5}X_5 + \tau_6\widetilde{P_6}X_6 \tag{17}$$

$$max\ GRP \tag{18}$$

2.10 Case Setting

We set three cases as shown in Table 2. Case0 is the baseline case. In case1, new waste treatment industries are introduced but there is no tax-subsidy policy. In case2, waste discharging tax is implemented. The tax is a specific duty which is imposed on discharged amount of waste. All the money collected by the tax is spent as subsidy to Waste treatment industries in Tokyo and New waste treatment industries in Tokyo.

Table 2. Case setting

	New industries	Tax-subsidy
case0	✕	✕
case1	✓	✕
case2	✓	✓

In the next chapter, with GHG emissions restriction at the 2011 level in case0 is referred to as case0 (0%), and we analyze the results with case0 (0%) as the standard.

3. Simulation Results

3.1 Effect of Introducing New Industries

Figure 5 shows changes in GRP and Gross Domestic Product (GDP) along with GHG emissions restriction. In case0 (0%) which is baseline case and GHG emissions amount is 2011 level, GRP is 99 008 680 million yen and GDP is 553 089 100 million yen while the actual value in 2011 is 100 868 188 million yen for GRP and 548 754 636 million yen for GDP. Differences between value of simulation result and actual value for GRP and GDP are 1.84% and 0.79%, respectively. Therefore, we consider that the simulation model used in the research and the results are valid. In case0, we got result only with restriction on GHG emissions till -6% of that of 2011. Meanwhile we got till -14.5% for case1 which is case with new industries. In both cases, GRP and GDP fell down as we tighten up GHG emissions restriction. However in case1, economic level was kept higher than case0 (0%) till -8% GHG emissions restriction. These indicate that deterioration in economic scale was suppressed by introduction of new industries. Here -8% GHG emissions restriction equals to only 3.5% GHG emissions reduction from 2000 level, which cannot fulfill the GHG reduction target of -25% from 2000 level.

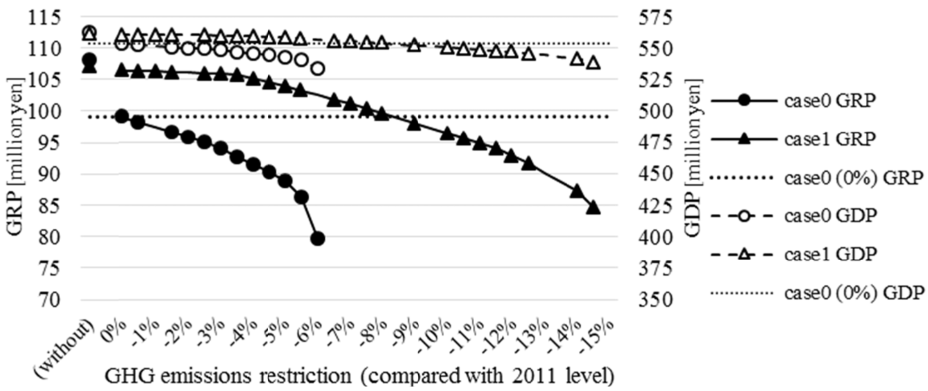

Figure 5. Change in GRP and GDP along with GHG emissions restriction

Figure 6 shows final disposal amount when there is no restriction and with 0% restriction in case0 and case1. Numbers shown in the figure is ratio of all the cases to case0 (0%). Compared with case0 (0%), final disposal amount was reduced by 4.2% with introduction of new industries.

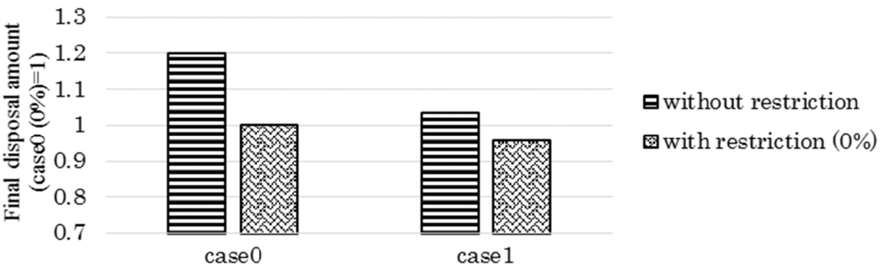

Figure 6. Final disposal amount with case0 and case1

3.2 Effect of Introducing Tax and Subsidy

Figure 7 shows results of case2. In case2, we were unable to get results when tax rate is more than 70 yen/kg. We got results of tax rate of 1 yen/kg, 10 yen/kg, 30 yen/kg, 50 yen/kg and 70 yen/kg. Numbers in vertical axis represent ratio of final disposal amount per GRP to case0 (0%). With tax rate of 10 yen/kg and 50 yen/kg, the numbers were kept less than 0.9 from 0% GHG emissions restriction.

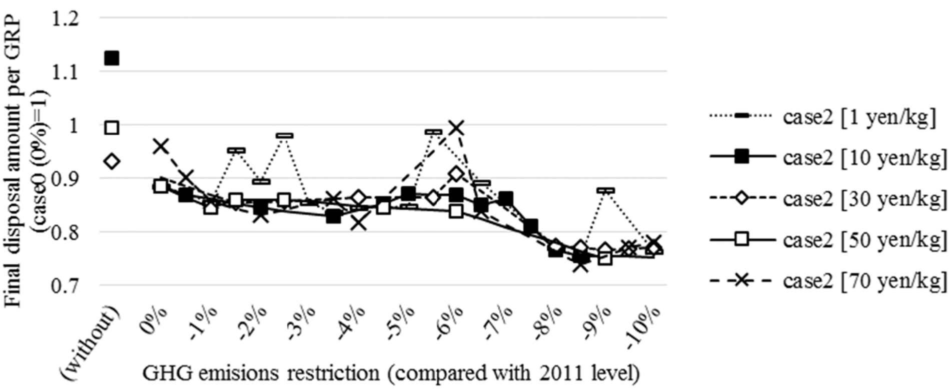

Figure 7. Change in final disposal amount per GRP with case2

Results of case2 [10 yen/kg] and case2 [50 yen/kg] show that final disposal amount reduced by 5% and final disposal amount per GRP reduced by around 11% (see Table 3). The values rose when there is -6% or -8% GHG emissions restriction. In Tokyo, depending on region and types of waste, waste discharging tax is set to at most 50 yen/kg. Taking into account both the effects and social acceptancy, 10 yen/kg was optimal tax rate.

Table 3. Values of case2 compared with case0 (0%)

	case0	case2 [10 yen/kg]			case2 [50 yen/kg]		
	(0%)	(0%)	(6%)	(8%)	(0%)	(6%)	(8%)
Final disposal amount	1	0.9504	0.8987	0.7711	0.9504	0.8678	-
Final disposal amount per GRP	1	0.8861	0.8677	0.7670	0.8845	0.8379	-

Production of each industry of case2 [10 yen/kg] (8%) had not much difference among case0 (0%) and case1 (8%) (see Figure 8). On the other hand, households' consumption in case2 [10 yen/kg] (8%) fell down by 7.2% and 7.0% compared with case0 (0%) and case1 (8%) respectively. These results revealed that introduction of waste discharging tax and subsidy had more effects on households than on industries.

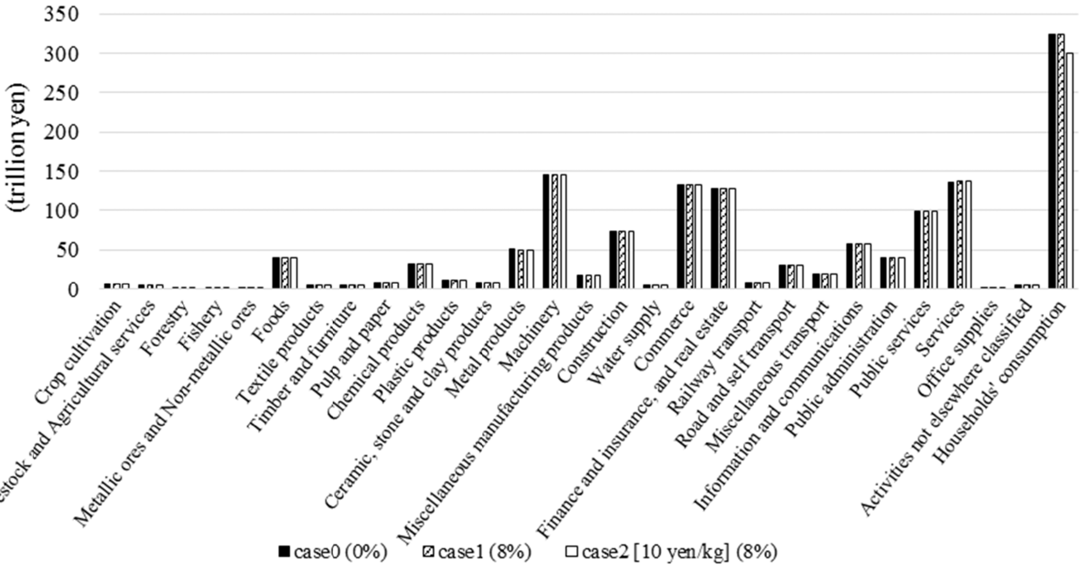

Figure 8. Production of each industry and consumption

4. Conclusions

In this study, we clarified the effects of thorough waste recycling on economy and environment. We selected Tokyo Metropolitan City as the study area. Focusing on utilization of waste, we conducted an interregional input-output model which takes into account economic activities of not only Tokyo Metropolitan City but also other region. The model includes economic activity structure, balance of waste flow, amount of GHG and balance of energy flow. With restriction on GHG emissions amount, we conducted computer simulation. The results show that promotion of waste recycling contributed with keeping economic level above the baseline till -3.5% GHG emissions reduction from 2000 level. When we implemented tax-subsidy policy with tax rate of 10 yen/kg, both final disposal amount and final disposal amount per GRP were kept lower than the baseline case. However, only promoting waste recycling was not enough to improve the environment. The GHG reduction target, which is -25% from 2000 level, was unable to be achieved only through promotion of waste recycling. We also have to promote other environmental countermeasures to meet the target.

Therefore our future work includes other types of renewable energy such as solar power and wind power in order to achieve the target set by Tokyo Metropolitan Government. Moreover, when we utilize biomass, not only GHG emissions but also water pollutants can be reduced. Besides while thinking of utilizing waste, it is important to consider the size and allocation of treatment facility because there is a trade-off relation between transportation cost and environmental pollution. We will further conduct comprehensive evaluation with equations for transportation network problem to the model and using different indexes such as water pollution and air pollution.

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