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HOW DOES MUNICIPAL SOLID WASTE POLICY AFFECT HEAT AND ELECTRICITY PRODUCED BY INCINERATORS?

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ABSTRACT

This study examines the effects of municipal solid waste (MSW) policy interventions, specifically sorted collections and unit-based pricing of heat and electricity produced by incinerators in Japan, considering technological and demographic factors. The study shows that the technological factors such as incineration capacity and 24 hours operation affect the available heat energy and electricity. In addition, some sorted collections and unit-based pricing have also affected them. Sorted collections of organic waste can increase available heat energy. For plastics containers and packaging, no significant effects have been observed for both heat energy and electricity. In contrast, for sorted collections of paper containers and packaging, negative significant effects have been observed for both heat energy and electricity. This phenomenon indicates that other factors than a decrease in lower calorific values may affect the heat energy and electricity. Operating years has affected electricity negatively though it has affected heat energy positively. These findings indicate that proper make-decision of MSW policy and choice of incineration type depend on whether which option the municipalities focus on either material recycling or energy recovery (either heat energy or electricity).

1. INTRODUCTION

Sorted collection and recycling of municipal solid waste (hereafter, MSW) is widely practiced in most developed countries. In Japan, an increasing number of municipalities collect plastic and paper containers and packaging separately, since the entire implementation of the Containers and Packaging Recycling Law in 2000. Unit-based pricing is also widely introduced in most developed countries to promote 3R (reduce, reuse, recycle). In Japan, approximately 63% of municipalities implement unit-based pricing as of April 2017 (from the website of professor Yamaya, http://www2.toyo.ac.jp/~yamaya/survey.html - Japanese).

Further, it is expected that incinerators will play an important role as waste-to-energy (hereafter, WTE) plants, in order to produce energy in the form of heat and electricity in many countries (Persson and Munster, 2016; Psomopoulos et al., 2009; Tomic et al., 2016; Xing–gang et al., 2016). In Japan, there have been higher expectations on renewable energy including WTE since the major earthquake and tsunami on March 11, 2011. Although most MSW is burned in Japan, the amount of heat and electricity produced by incinerators is not substantial (Takaoka et al., 2011). As shown in Figure 1, two thirds of incinerators utilize heat and/or electricity produced by them. The figure shows that electricity utilization tends to increase recently. However, the scale is smaller than WTEs in the EU countries and the United States (ISWA 2015). In addition, off-site utilization is still limited. After the implementation of the feed–in tariff (hereafter, FIT) scheme in 2012, electricity originating from renewable energy sources such as biomass including waste is purchased at a fixed price and for a long-term period by existing electric utilities in Japan (METI 2012).

Waste with high calorific values and more waste are suitable for augmenting energy supplies. In that context, separation of organic waste could be superior to that of waste plastic and paper. On the other hand, Psomopoulos et al. (2009) showed that the WTE communities achieved a higher recycling rate than an average recycling rate, referring to the data by the US Environmental Protection Agency.

From another point of view, technological factors such as incineration capacity of incinerators and demographic factors such as population density can also affect energy supplies produced by incinerators. Therefore, it is important to examine the relationships between MSW policy, technology, demographic factors, and energy production for proper make-decision of MSW policy and choice of incineration type. However, no existing studies provide comprehensive empirical evidence as to the relationships between them.

Therefore, this study examines the effects of MSW policy interventions, specifically sorted collections and unit-

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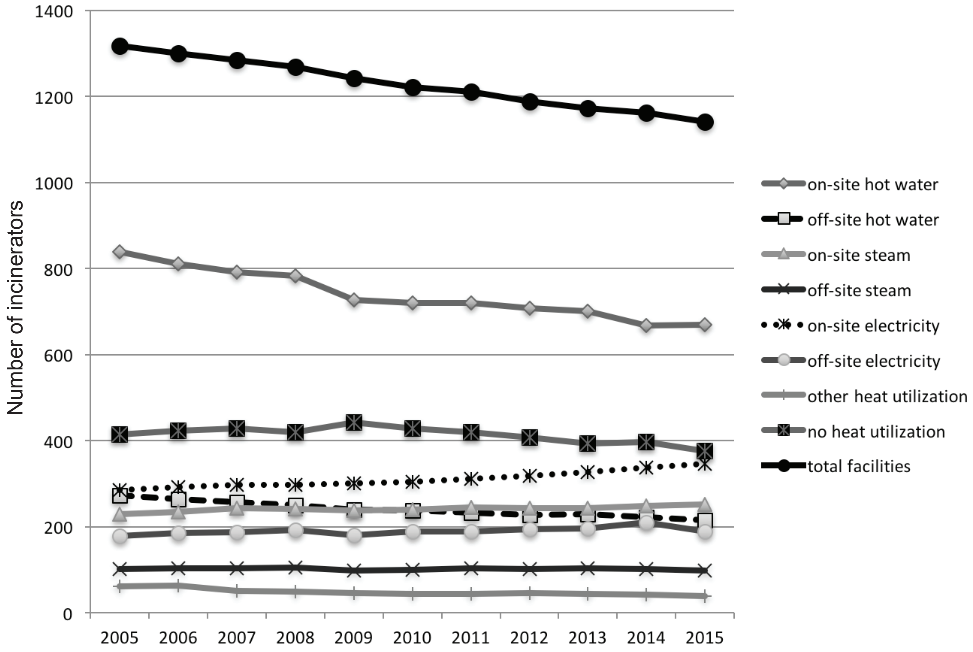

FIGURE 1: Trend of incinerators that produce heat and electricity in Japan. Note: The sum of the numbers in each item is not the same as the number of total facilities because some incinerators have more than one function. Source: Ministry of the Environment, Japan.

based pricing of heat and electricity produced by incinerators in Japan, considering technological and demographic factors.

2. LITERATURE REVIEW

Holmgren and Henning (2004) compared material recovery with waste incineration and subsequent energy recovery for an energy-efficiency case study focusing on two Swedish municipalities. They showed that paper and hard plastics should be materially recovered while cardboard and biodegradable waste was more suited for energy recovery. Calabro (2009) examined the relationship between carbon dioxide emissions released from incinerators and separate collection of MSW. He noted that separate collection of plastics is a key issue when residual waste is treated in WTE plants considering greenhouse gases emission. He showed that the potential increase in energy production due to co-incineration of waste plastics and other combustibles would not offset the increase in carbon dioxide emission from incinerators, though it increases with lower calorific values (hereafter, LCVs) of waste. Calabro (2010) evaluated the effect of separate collection on the characteristics of residual MSW in terms of LCVs and ash production in Italy. He showed that water content of residual waste and the share of combustible materials were affected by separate collection. However, while these existing studies considered the characteristics of the residual waste, they did not consider technological (e.g., incineration types and capacity) or demographic factors.

Nishitani et al. (2010) simulated the effects of sorted collection and recycling on the volume and composition of waste, based on the changes observed in two Japanese municipalities that had actually introduced sorted collection. They found that a decrease in calorific value would be limited though the share of combustibles in waste would decrease due to sorted collection and depopulation. However, they did not examine heat and electricity produced by incinerators while they focused on the future composition. Takaoka et al. (2011) examined various scenarios involving indirect reduction of carbon dioxide emissions by WTE plants in Japan. Although they focused on technical determinants such as enhancement of energy recovery capacity, they did not consider policy or demographic determinants. Additionally, none of these studies considered plant–variant or time-variant factors.

Tomic et al. (2016) indicated that changes in EU legislation (such as 99/31/EC on landfill of waste, 2008/98/EC on basic concepts of waste management, and 2012/27/EU on energy efficiency) affect the amount and composition of MSW, and WTE plants could improve their profitability by co-combusting other local wastes and introduction of area-wide waste management. However, no existing studies provide comprehensive empirical evidence as to the relationships between MSW policy, technology, demographic factors, and energy production.

3. METHODOLOGY AND DATA

3.1 Methodology

This study uses a parametric approach to estimate factors that can affect heat and electricity produced by incinerators. It invokes independent variables that capture the following three sets of determinants: MSW policy, technological factors and demographic characteristics. Further, models are delineated based on the following five dependent variables: (1) available heat energy; (2) utilized heat energy out of incinerators in (1); (3) available electricity; (4) utilized electricity out of incinerators in (3); and (5) LCVs. The last dependent variable (5) is considered to examine whether the independent variavles affect the characteristics of residual MSW in terms of LCVs or not. The actual (not nominal) values for these five variables are used on a priority basis in the study. When plants do not report the actual values, the study uses the nominal values. The study focuses on WTE plants for MSW that produce heat and/or electricity in Japan. However, some zero values are included in the dependent variable data arrays because some plants have either heat or power generation facilities. Of note, the number of the plants that supply heat and electricity outside of the plants is small. Some missing data are also included therein because a few plants do not report the actual data of utilized heat and electricity. In this case (censored data), ordinary least squares regression leads to inconsistent parameter estimates. Therefore, excluding (5) LCVs, the study applies a Tobit regression analysis to examine the foregoing determinants. As for (5), many plants have positive values of the actual or nominal values though a few plants do not report the both. Therefore, the study applies a normal panel regression for (5). Importantly, panel data are utilized which control for omitted variables, with consideration of time-variant factors.

The model structure of Tobit regression is as follows (Cameron and Trivedi, 2009):

$$WTE_i^{j*} = X_i^{j'}\beta_X + Y_i^{j'}\beta_Y + Z_i^{j'}\beta_Z + \varepsilon_i^j, \quad i = 1, \dots, N, \ j = 1, 2 \dots, 5$$

where $\varepsilon_i^j \sim N(0, \sigma^2)$, and WTE_i^{j*} is an unobserved latent variable for the i-th facility and for the j-th dependent variables - above (1) to (5). X_i^j, Y_i^j and Z_i^j denote the $(K \times 1)$, $(L \times 1)$ and $(M \times 1)$ vectors of exogenous and fully observed regressors for technological factors, MSW policy and demographic characteristics, respectively. The concrete elements of each factor are presented in the next subsection. K, L and M represent the number of independent variables in each determinant.

The observed variable WTE_i^j is related to the latent variable WTE_i^{j*} in the case of left−censored Tobit model as follows:

$$WTE_i^j = \begin{cases} WTE_i^{j*} & \text{if } 0 \leq WTE_i^{j*} \\ 0 \text{ if } & WTE_i^{j*} < 0 \end{cases}$$

In actual estimation, the dependent variables are transformed by logarithms to capture (semi-)elasticity.

3.2 Data

635 incinerators (WTE plants) for MSW disposal in Japan were originally selected; they are the plants that were operating during 2007 to 2015. The data is an unbalanced panel because the plants are included if they operated in at least any two years during the period.

The study considers separation of plastic containers and packaging, paper containers and packaging, and organic waste, and unit-based pricing as the MSW policy. These are treated as dummy variables that take the value 1 if each policy is implemented in the municipality where the incinerator locates. Unit-based pricing is expected to promote waste separation because it generally increases the burden on burnable and unburnable waste other than recycling, and in contrast, it lightens the burden on recycled waste. In addition, it is expected to decrease the amount of waste disposal. With or without co-disposable industrial waste is also considered. It is treated as a dummy variable that takes the value 1 if co-disposable industrial waste is done in the incinerator. Industrial waste is disposed of separately from MSW, in principle, in Japan. Considering economic efficiency, however, some MSW incinerators dispose of industrial waste which consists of the same properties as MSW. Co-disposal of industrial waste and MSW may also increase energy efficiency.

Incineration type (whether melting treatment or not and 24 hours operation or not), incineration capacity and operating years are considered as the technological factors, referring to existing studies (e.g., Takaoka et al., 2011). Melting treatment is treated as a dummy variable that takes the value 1 if the incinerator adapts the incineration type. 24 hours operation is also treated as a dummy variable that takes the value 1 if the incinerator operates continuously for 24 hours per day. It is likely to produce more energy because waste is disposed of at higher temperatures and stably in case of melting treatment and 24 hours operation. If there are economies of scale, larger incineration capacity would produce more energy. Older plants are likely to be less energy efficient and produce less power, superseded because of technological innovation.

In addition, population density in the municipalities is considered as a demographic factor. It is likely that heat energy tends to be utilized in denser areas. Annual average outside temperature is also considered as a geographic factor. Kakuta (2010) shows that the lower outside temperature is, the less energy is produced. This is because some incinerators use heat for white vapor smoke prevention to mitigate residents' anxiety in Japan. Therefore, it is likely to decrease power generation and the outside supply of heat energy. On the other hand, the outside supply of heat energy may increase in colder areas because such areas can have a strong demand for that. Time trend is controlled using year dummy variables.

Waste management data pertaining to (1) to (5) above, as well as data pertaining to technological factors and MSW policy are taken from the website of the Ministry of the Environment, Japan (http://www.env.go.jp/recycle/waste_tech/index.html - Japanese). Population densities in each municipality are taken from the database hosted by the Asahi Shinbun Syuppan (a Japanese newspaper company) (2014) and the websites of the Ministry of Internal Affairs and Communications (http://www.stat.go.jp - Japanese). Outside temparature in each municipality are taken from the websites of the Japan Meteorological Agency (http://www.jma.go.jp/jma/index.html - Japanese).

Correlation coefficients indicate that the relationships between the explanatory variables are negligible. Descriptive statistics are shown in Table 1.

Focusing on the policy variables, the table shows that the occurrence rates for the separation of plastics and paper are high while those for the separation of organic waste and co-disposal of industrial waste are low. For the technological factors, the melting treatment has not been common yet.

There are two main formulations for extensions of the truncated regression model to panel data similar to the lin-

TABLE 1: Descriptive statistics.

Variables	Mean	P50	SD	Max	Min
Heat energy (MJ)	6.56E+07	712515	2.00E+08	3.24E+09	0
Outside supply of heat (MJ)	5924437	0	3.27E+07	6.99E+08	0
Electricity (MWh)	41797.18	15627	641757.3	2.74E+07	0
Outside supply of electricity (MWh)	89022.96	2185.5	2503995	9.72E+07	0
Lower calorific values (kJ/kg)	8566.47	8602	2154.38	22430	0
Incineration capacity (ton / day)	238.46	170	216.48	1800	7
24 hours operation (D)	0.78	1	0.42	1	0
Operating years	15.64	15	8.30	43	0
Melting treatment (D)	0.15	0	0.35	1	0
Separation of plastics containers and packaging (D)	0.66	1	0.47	1	0
Separation of paper containers and packaging (D)	0.68	1	0.46	1	0
Separation of organic waste (D)	0.08	0	0.26	1	0
Unit-based pricing (D)	0.40	0	0.49	1	0
Co-disposal of industrial waste (D)	0.18	0	0.38	1	0
Population density (100 person / km^2)	22.86	7.60	35.11	153.71	0.06
Average outside temperature (°C)	15.51	16.20	2.60	24.10	4.30

Note: (D) represents a dummy variable.

ear regression: fixed effects and random effects models. The study applies the random effects model for the following two reasons. First, the study includes time−invariant independent variables. Second, it does not seem to be unrealistic that the individual-specific effect is not correlated with the independent variables in the study because plant manufactures that manage all over the country build incinerators.

4. ESTIMATION RESULTS

The estimation results from a random effects Tobit regression are shown in Tables 2 and 3. Table 2 presents the results of heat energy and outside supply in it, and Table 3 presents those of electricity and outside supply in it. The results of the likelihood-ratio test and ρ, percent contribution to the total variance of the panel-level variance component, indicate that we should not use pooled data, but panel data. The estimation results of LCVs from a standard panel (random effects) regression are shown in Table 4. The results of the Hausman test and Breusch-Pagan test indicate that we should not use fixed effects, but random effects model. For each dependent variable, the estimation results for a case including all explanatory variables are shown in columns “Model 1”, and the results after elimination of insignificant variables are shown in the columns “Model 2”.

The parameters represent the effects of a change in each independent variable on the expected value of the latent variable WTE_i^{j*}, holding all other independent variables constant (Breen 1996). They also indicate the marginal effects in the mean of each variable among the uncensored observations because the heat energy and electricity including outside supply of them are transformed by logarithms, as noted Subsection 3.1. Positive values indicate more supply of heat energy or electricity in Table 2 and 3, and more LCVs in Table 4. Negative values indicate the opposite phenomena. The following are the estimation results of Model 2 for each energy utilization.

4.1 Heat energy

Significant variables that affect the available heat energy among the technological factors are incineration capacity, 24 hours operation (only outside supply) and operating years, which are significantly positive, and melting treatment (only available heat energy), which is significantly negative. One ton increase in incineration capacity increases heat energy and outside supply of it by 1.5% and 3.4%, respectively. 24 hours operation increases outside supply of heat energy by 245.0% though it does not affect the heat supply significantly. These findings are similar to the study’s a priori expectation. One year increase in operating years increases heat energy and outside supply of it by 9.0% and 26.0%. Positive effect of operating years does not accord with a priori expectation because it was expected that newer incinerators tended to generate more energy. This phenomenon will be discussed with the results of electricity in the next subsection. The results indicate that melting treatment decreases heat energy by approximately 404.9% though it does not affect the outside supply of heat significantly. Although this finding is contrary to a priori expectation, the plants with melting treatment are likely to have put a high priority on producing more electricity rather than heat energy to offset the increase of electricity with melting treatment . However, melting treatment is not significant for the electricity (though positive sign), as noted in the next subsection.

Significant variables that affect heat energy among the policy determinants are the separation of organic waste, which is significantly positive, and the separation of paper containers and packaging, which is significantly negative.

TABLE 2: Estimation results of heat energy.

	Heat energy		Outside supply of heat	
	Model 1	**Model 2**	**Model 1**	**Model 2**
Incineration capacity	0.0146	0.0147	0.0335	0.0341
	[6.59]***	[6.92]***	[8.03]***	[8.20]***
24 hours operation (D)	−0.2351	N.S.	2.3725	2.4503
	[−0.33]		[1.91]*	[2.02]**
Operating years	0.0891	0.0900	0.2284	0.2596
	[2.47]**	[2.50]**	[4.12]***	[5.29]***
Melting treatment (D)	−4.0731	−4.0493	−2.7671	N.S.
	[−3.79]***	[−3.81]***	[−1.66]*	
Separation of plastics containers and packaging (D)	0.0450	N.S.	0.5723	N.S.
	[0.10]		[0.85]	
Separation of paper containers and packaging (D)	−0.9626	−1.0254	−0.8328	N.S.
	[−2.43] **	[−2.61]**	[−1.41]	
Separation of organic waste (D)	1.1779	1.4053	−0.6372	N.S.
	[1.88]*	[2.25]**	[−0.68]	
Unit-based pricing (D)	−0.5045	N.S.	−1.8466	−1.9540
	[−1.07]		[−2.41]**	[−2.56]***
Co-disposal of industrial waste (D)	0.9488	N.S.	0.6816	N.S.
	[1.56]		[0.78]	
Population density	−0.0920	−0.0938	−0.0871	−0.0770
	[−6.47]***	[−6.83]***	[−3.82]***	[−3.49]***
Outside temparature	−0.1154	N.S.	0.5584	N.S.
	[−0.74]		[2.16]**	
Year 2008 (D)	−0.2610	N.S.	-0.3851	N.S.
	[−0.58]		[-0.57]	
Year 2009 (D)	3.4703	3.5443	1.9758	2.1266
	[8.02]***	[9.64]***	[3.01]***	[3.79]***
Year 2010 (D)	5.1546	5.0231	2.2958	3.5231
	[10.07]***	[13.48]***	[2.91]***	[6.27]***
Year 2011 (D)	4.7731	4.8843	2.9631	2.9905
	[10.51]***	[12.73]***	[4.31]***	[5.18]***
Year 2012 (D)	5.7226	5.8365	3.9437	3.8616
	[12.25]***	[14.89]***	[5.59]***	[6.61]***
Year 2013 (D)	6.1886	6.2401	4.0919	4.1191
	[12.93]***	[15.33]***	[5.71]***	[6.86]***
Year 2014 (D)	5.9722	6.0684	4.1431	3.9949
	[12.05]***	[14.39]***	[5.53]***	[6.45]***
Year 2015 (D)	5.1108	5.1210	3.0859	3.1995
	[10.02]***	[11.57]***	[4.04]***	[4.94]***
Constants	3.7603	1.7355	−37.1015	−29.9631
	[1.46]	[2.03]**	[−6.68]***	[−20.52]***
ρ	0.6957	0.6946	0.9139	0.9138
Num. of observations	5098		5098	
Num. of groups	635		635	
Log likelihood	−12826.52	−12847.67	−5990.74	−5995.10
Wald test	χ^2(19) = 640.02***	χ^2(13) = 634.24***	χ^2(19) = 291.08***	χ^2(12) = 281.99***
Likelihood-ratio test	3044.8***	3074.61***	3718.59***	3760.39***
Left−censored observations	1719		3624	
Uncensored observations	3379		1474	

Note: (D) represents a dummy variable. N.S. represents not significant. Values in square brackets represent z−statistics.
**** p < 0.01, ** p < 0.05, * p < 0.1.*

TABLE 3: Estimation results of electricity.

	Electricity		Outside supply of electricity	
	Model 1	**Model 2**	**Model 1**	**Model 2**
Incineration capacity	0.0219	0.0222	0.0203	0.0201
	[20.78]***	[21.01]***	[11.11]***	[11.09]***
24 hours operation (D)	1.0129	1.0371	10.7159	10.7882
	[5.01]***	[5.27]***	[5.17]***	[5.18]***
Operating years	−0.2701	−0.2782	−0.2581	−0.2665
	[−26.04]***	[−30.09]***	[−8.41]***	[−9.33]***
Melting treatment (D)	0.5777	N.S.	0.6980	N.S.
	[1.61]		[0.76]	
Separation of plastics containers and packaging (D)	0.0665	N.S.	−0.0792	N.S.
	[0.61]		[−0.21]	
Separation of paper containers and packaging (D)	−0.3799	−0.3811	0.6589	0.6372
	[−3.91]***	[−3.98]***	[1.78]*	[1.75]*
Separation of organic waste (D)	0.2736	N.S.	0.3641	N.S.
	[1.62]		[0.58]	
Unit-based pricing (D)	−0.1021	N.S.	0.7401	N.S.
	[−0.75]		[1.56]	
Co-disposal of industrial waste (D)	0.3084	0.3077	−0.2816	N.S.
	[2.14]**	[2.15]**	[−0.55]	
Population density	0.0138	0.0149	0.0377	0.0363
	[2.41]**	[2.73]***	[3.42]***	[3.48]***
Outside temparature	−0.0126	N.S.	0.1172	N.S.
	[−0.22]		[0.78]	
Year 2008 (D)	0.3520	0.3701	−13.2191	N.S.
	[3.25]***	[3.53]***	[−0.02]	
Year 2009 (D)	0.5931	0.5966	16.3349	17.1840
	[5.59]***	[5.76]***	[14.87]***	[16.63]***
Year 2010 (D)	0.8370	0.8326	16.8220	17.8756
	[5.901]***	[7.87]***	[14.91]***	[17.26]***
Year 2011 (D)	1.1542	1.1805	17.3675	18.1960
	[10.15]***	[10.93]***	[15.72]***	[17.52]***
Year 2012 (D)	1.4515	1.4894	18.2500	19.0855
	[12.20]***	[13.50]***	[16.44]***	[18.32]***
Year 2013 (D)	1.7529	1.7858	18.8392	19.7287
	[14.60]***	[15.73]***	[16.94]***	[18.87]***
Year 2014 (D)	2.0186	2.0608	17.5878	18.4600
	[15.84]***	[17.55]***	[15.72]***	[16.88]***
Year 2015 (D)	2.1120	2.1585	16.8327	17.7946
	[16.49]***	[17.75]***	[15.02]***	[16.88]***
Constants	−2.6329	−3.0530	−36.0411	−34.6020
	[−2.93]***	[−11.42]***	[−10.67]***	[−13.95]***
ρ	0.9662	0.9683	0.8413	0.8411
Num. of observations	5098		5098	
Num. of groups	635		635	
Log likelihood	−5627.11	−5623.87	−4230.96	−4236.30
Wald test	$\chi^2(19) = 1552.90$***	$\chi^2(19) = 1570.45$***	$\chi^2(19) = 607.48$***	$\chi^2(12) = 657.74$***
Likelihood-ratio test	7325.02***	7331.76***	2152.55***	2188.95***
Left-censored observations	2453		3820	
Uncensored observations	2645		1278	

Note: (D) represents a dummy variable. N.S. represents not significant. Values in square brackets represent z-statistics.
**** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.*

TABLE 4: Estimation results of lower calorific values (LCVs).

	Model 1	Model 2
Incineration capacity	0.0001	0.0001
	[1.78]*	[1.72]*
24 hours operation (D)	0.0998	0.0990
	[4.19]***	[4.30]***
Operating years	−0.0028	−0.0028
	[−2.91]***	[−1.99] **
Melting treatment (D)	0.0056	N.S.
	[0.25]	
Separation of plastics containers and packaging (D)	−0.0288	−0.0294
	[−2.37]**	[−2.47]**
Separation of paper containers and packaging (D)	−0.0278	−0.0273
	[−2.00]**	[−1.99]*
Separation of organic waste (D)	0.0026	N.S.
	[0.11]	
Unit-based pricing (D)	0.0176	N.S.
	[1.38]	
Co-disposal of industrial waste (D)	−0.0007	N.S.
	[−0.03]	
Population density	0.0012	0.0011
	[5.88]***	[5.77]***
Outside temparature	-0.0006	N.S.
	[−0.17]	
Year 2008 (D)	−0.0916	−0.0998
	[−5.79]***	[−7.06]***
Year 2009 (D)	0.0175	N.S.
	[1.16]	
Year 2010 (D)	0.0696	0.0602
	[4.09]***	[5.24]***
Year 2011 (D)	0.0637	0.0557
	[4.14]***	[4.54]***
Year 2012 (D)	0.0847	0.0772
	[5.94]***	[6.86]***
Year 2013 (D)	0.1178	0.1105
	[8.02]***	[9.44]***
Year 2014 (D)	0.1058	0.0988
	[6.81]***	[7.68]***
Year 2015 (D)	0.0934	0.0863
	[4.54]***	[4.70]***
Constants	8.9318	8.9427
	[148.05]***	[384.78]***
Num. of observations	4988	
Num. of groups	635	
Hausman test	$\chi^2(19) = 25.18$	$\chi^2(13) = 18.77$
	p = 0.154	p = 0.131
Breusch-Pagan test	$\chi^2(1) = 1677.02$	$\chi^2(1) = 1733.98$
	p = 0.000***	p = 0.000***

Note: (D) represents a dummy variable. N.S represents not significant. Values in square brackets represent z−statistics.
**** p < 0.01, ** p < 0.05, * p < 0.1.*

The results indicate that the separation of organic waste increases heat energy by approximately 140.5%, while the separation of paper containers and packaging decreases it by approximately 102.5%, which are similar to a priori expectation. A significant variable that affects the outside supply of heat energy among the policy determinants is the unit-based pricing, which is significantly negative. The unit-based pricing decreases the outside supply of heat energy by approximately 195.4% though it has not affected available heat energy significantly. This phenomenon will be also discussed with the results of electricity in Subsection 4.3. Co-disposal of industrial waste and MSW has not affected heat energy and the outside supply of it significantly so far.

Population density is negatively significant for heat energy. The results suggest that 100 people increase per km^2 in population density decreases heat energy and outside supply of it by 9.4% and 7.8%, respectively. This indicates that heat energy tends to be utilized in sparser areas. Agricultural utilization such as greenhouses may increase heat energy in sparser areas. Outside temparature has not affected heat energy and the outside supply of it significantly. The year dummies after 2009 are positively significant for heat energy (including the outside supply of it). Possible reasons of positive effects observed in the year dummies are as follows. The ministry of the environment has abolished state subsidy for siting incinerators without energy recovery, and raised the portion of state subsidy for siting WTEs that can produce heat and electricity highly efficiency since 2005. This incentive for siting WTEs may promote energy recovery with a time lag of a few years. In addition, the major earthquake and tsunami in Japan on March, 2011 is likely to increase outside supply of energy produced by incinerators because of making up for temporal loss of energy supply after the earthquake.

4.2 Electricity

Significant variables that affect electricity among the technological factors are 24 hours operation and incineration capacity, which are significantly positive, and operating years, which is significantly negative. These findings are similar to a priori expectation. The results indicate that one ton increase in incineration capacity increases electricity and outside supply of it by 2.2% and 2.0%, respectively. These findings indicate that 24 hours operation contributes to more electricity generation and there are economies of scale in production of both heat and electricity in the incinerators. 24 hours operation increases electricity and outside supply of it by approximately 103.7% and 1078.8%, respectively. Most of the plants that supply electricity outside the incinerators operate for 24 hours. This seems to bring significant differences of more than ten times between with and without 24 hours operation. One year decrease in operating years decreases electricity and outside supply of it by 27.8% and 26.7%, respectively. Old incinerators are likely to have put a high priority on producing more heat energy rather than electricity, considering the results in the previous subsection. This phenomenon seems to be caused by the implementation of the RPS (Renewables Portfolio Standard) that mandates electric utilities to use a fixed minimum amount of renewable energy sources in 2003, and FIT in 2012. On the other hand, melting treatment has not affected the electricity significantly.

Significant variables that affect the electricity among the policy factors are the separation of paper containers and packaging, which is significantly negative, and co-disposal of industrial waste and MSW, which is significantly positive. A significant variable that affects the ouside supply of electricity among the policy factors is the separation of paper containers and packaging, which is significantly positive. The results indicate that the separation of paper containers and packaging increases the outside supply of electricity by 63.7% though it decreases electricity by 38.1%. It should be noted that some incinerators purchase electricity from outside equal to or than the amount of electricity produced by the incinerator, as noted by Matsuto (2012). On the other hands, the results suggest that sorted collection of plastics containers and packaging and organic waste has not affected the electricity significantly. These findings will be further examined considering LCVs in the next subsection.

Population density is positively significant for electricity. The results suggest that 100 people increase per km^2 in population density increases electricity and outside supply of it by 1.5% and 3.6%, respectively. This indicates that electricity tends to be utilized in denser areas similarly to a priori expectation. It is likely that there is a stronger need for electricity in urban areas. This phenomenon is contrary to the results of heat energy noted in the previous subsection. Outside temparature has not affected electricity and the outside supply of it significantly. The year dummies after 2008 or 2009 (for the outside supply of electricity) are positively significant for electricity. Possible reasons of positive effects observed in the year dummies are similar to the points noted in the previous subsection. In addition, it is likely that the implementation of the RPS and FIT promotes more electricity generation.

4.3 Lower Calorific Values (LCVs)

Significant variables that affect LCVs among the technological factors are 24 hours operation and incineration capacity, which are significantly positive, and operating years, which is significantly negative. These findings are similar to a priori expectation. The results indicate that one ton increase in incineration capacity increases LCVs by 0.01%. 24 hours operation increases LCVs by approximately 9.9%. One year decrease in operating years decreases LCVs by 0.3%. These findings indicate that the fluctuation of LCVs affects heat energy and electricity.

Significant variables that affect LCVs among the policy factors are the separation of plastic and paper containers and packaging, which are significantly negative. The results indicate that the separation of plastic and paper containers and packaging decreases LCVs by 2.9 and 2.7%, respectively. These findings are similar to a priori expectation. However, there is no significant difference between the both rates though the calories of plastics are higher than those of paper in general. On the other hand, the separation of plastic containers and packaging has not decreased both heat energy and electricity significantly as mentioned in the previouse subsections, even though a decrease in LCVs was observed. This result is similar to the result by Nishitani et al. (2010). In contrast, the separation of paper containers and packaging has decreased both heat energy and electricity. In addition, a decrease in energy recovery is much larger than that in LCVs. This phenomenon indicates that other factors than LCVs may affect the heat energy and electricity. However, this study cannot clarify the factors. The results also suggest that unit-based pricing has not affected LCVs significantly so far. On the other hand, it has been negatively significant on the outside supply of electricity though it has not affectd the available electricity significantly, as shown in the previous subsection. This phenomenon also indicates that other factors than LCVs may affect the outside supply of electricity. A possible reason of negative effects observed in the unit-based pricing is as follows. Unit-based pricing was originally introduced in rural areas, which have weeker need for electricity than urban areas. Such a geological characteristic may affect the outside supply of electricity.

Population density is positively significant for LCVs. This result indicates that LCVs are higher in urban areas rather than rural areas. This phenomenon seems to be caused by the volume of business waste and the life-style in urban areas. Some business wastes are included in MSW in Japan. The rate of business waste tends to be higher in denser areas rather than sparser areas (from the website of the Ministry of the Environment, http://www.env.go.jp/recycle/waste_tech/index.html - Japanese). Business waste is likely to contain more calofric waste such as papers. In addition, the residents in urban areas seem to consume more plastics and paper containers and packagings than those in the rural areas. In contrast, outside temparature has not affected LCVs significantly. The year dummies after 2010 are positively significant for electricity.

5. CONCLUSIONS

It is technological factors such as 24 hours operation and incineration capacity that mainly affect heat and electricity produced by incinerators. However, some MSW policy interventions such as sorted collections and unit-based pricing have affected them. Sorted collections of organic waste can increase available heat energy. For plastics containers and packagings, no significant effects were observed for both heat energy and electricity. In contrast, for sorted collections of paper containers and packaging, negative significant effects were observed for both heat energy and electricity. However, a decline of in energy recovery was much larger than that in LCVs. This phenomenon indicates that other factors than the change in LCVs may affect the heat energy and electricity. Clarification of these factors will be a further research. For unit-based pricing, a negative significant effect was observed for the outside supply of electricity though it has not affected the available heat, electricity and LCVs.

The results that sorted collections have provided a limited impact on LCVs and energy recovery may suggest that segregation by residents has not been perfect. Unlike can, glasses and PET bottoles, it is difficult for residents to segregate plastics and paper containers and packaging. If the residents can segregate them more perfectly, LCVs would decline more and therefore less energy might be produced.

These findings indicate that proper make-decision of MSW policy and choice of incineration type depend on whether which option the municipalities focus on either material recycling or energy recovery (either heat energy or electricity). Although the study focuses on quantitive changes of energy recovery, the financial and environmental effects are also important for a more detailed examination of sustainable waste management. This will be a further research.

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