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Development of CO_2 Emission Factors and Evaluation of Emissions from Municipal Solid Waste Incineration Facility

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In order to cope actively with the international environmental norms for the reduction of greenhouse gas emissions, it is required to estimate the national greenhouse gas emissions and develop country-specific greenhouse gas emission factor. In order to secure more accurate statistics of CO_2 emission from incineration facilities of the country's municipal solid wastes, this study compared and analyzed Tier 2a method applying the emission factor presented in the 2006 IPCC Guideline, Tier 3 method using the facility's characteristic value and CO_2 emission provided based on the actual measurement. The average Tier 2a CO_2 emission based on the Tier 2a method is 25,310tCO_2 eq/yr while that provided based on the Tier 3 method is 43,901tCO_2eq/yr, which suggests that the former is underestimated by 42% compared to the Tier 3 method. Comparing with the average CO_2 emission based on actual measurement, 36,269CO_2eq/yr, the estimate based on the Tier 2a method is 25,310CO_2 eq/yr, underestimated by 43 % compared with that provided based on actual measurement while the estimate generated from the Tier 3 method is 43,901CO_2 eq/yr, overestimated by 21 % compared with that from actual measurement. This difference comes from the fact that the estimate from the Tier 2a method is based on the basic value presented in the IPCC Guideline and that the difference between the Tier 3 method using the facility's unique material and the estimate from actual measurement comes from the consideration of composition of wastes, contents of dry substances, carbon contents in fossil fuels and variables affecting oxidation factors. Further study is still needed to determine accurate CO_2 emission rates from municipal solid waste incineration facilities and other various combustion facilities by obtaining country-specific emission factor, rather than relying on IPCC default emission factor. This study included the results of utilizing the waste characteristic values of single municipal solid waste incineration facilities. In the future, it is required to do continuous research and development on the estimation of CO_2 emissions and emission factors for various incineration facilities for the development of country-specific emission factors.

Key Words: Greenhouse gas, Incinerator, Municipal solid waste, Country-specific emission factor, CO_2 emissions, Emission factor.

INTRODUCTION

The Republic of Korea is a member of Climatic Change Convention and obliged to estimate and report national greenhouse gas emission[1].

The Republic of Korea, when estimating greenhouse gas emission statistics, applies the Tier 1 (simple method) basic value based on the IPCC Guideline (1996) while in some areas, the Tier 2 methodology is applied. However, the recently reported IPCC Good Practice Guidance (IPCC 2001) and 2006 IPCC Guideline recommend that in the event that a country has its own characteristic value, the country-specific emission factor is prioritized to the basic value. In advanced countries, studies are directed to secure such characteristic values[2].

In the event of insufficiency of materials related to emission factors presented in the 2006 IPCC Guideline, greenhouse gas emissions are estimated based on databases of advanced countries. On the other hand, the Tier 2 methodology is applied to areas where there are available materials while the presented statistics will basically choose results from the Tier 2 methodologies and areas where this is not possible use results from the Tire 1 methodology[3].

Hence, in order to secure more accurate statistics of CO_2 emission from facilities incinerating the country's municipal solid wastes, country-specific emission factors considering the characteristics of the country's municipal solid wastes rather than the basic values provided in the IPCC estimation standards shall be developed. Greenhouse emission gases generated from combustion of municipal solid wastes in incineration facilities include CO_2, CH_4 and N_2O. CO_2 takes up the largest part of them and is divided into biological wastes (biomass) and non-biological wastes coming from fossil fuels based on factors of properties[4]. The former consists of food, paper, wooden materials, animal and plant residues and sludges while the latter includes plastic, synthetics, rubber, leather and other combustible materials. CO_2 generated from incineration of biological wastes is considered to go through anabolism and reuse based on circulation in the natural system so is not included in the national greenhouse gas emission while CO_2 generated from incineration of non-biological wastes only will be included[5].

This study's analysis was based on the characteristic value of municipal solid wastes (MSW) from incineration facilities and estimated theoretical CO_2 emissions based on the Tier 2a and Tier 3 methods applying the 2006 IPCC Guideline. The estimate was compared against CO_2 emission from actual measurement.

EXPERIMENTAL

Selection of subject facilities: The subject facility for this study is selected among incineration facilities for daily wastes located in Cheon-an, Chung-nam, S.Korea. The facility incinerates 200 tons a day through continuous stoker incineration facilities, resulting in yearly incineration amounting to 58,000 tons and yearly heat amounting to about 530,000 GJ. Temperature for the incinerator is maintained around 950-1,200 ºC and the second combustion temperature is 850 ºC or higher, completely removing noxious pollutants.

TABLE-L
MSW WEIGHT INCINERATED DATA
IN THIS STUDY INCINERATOR

Year	2007	2008	2009	2010
Weight incinerated (Ton/yr)	56,677	57,319	58,154	58,080

In this study, CO_2 density in the emitted gases was measured through MK2 (Eurotron, Italy). The scope of measurement was 0-25 vol % O_2 and 0-100 vol % CO_2. O_2 was reduced to the standard oxygen concentration of 12 % while CO_2 was automatically deduced from a formula based on the measuring equipment according to factors by type of fuel. The flux was measured through M-5 Stack Sampler (CAE, U.S.A). The principle of measurement was to calculate velocity of flux based on measurement of dynamic pressure. The value was multiplied by sectional area to calculate flux. The scope of dynamic pressure for measurement was 0.0-5.0 in Aq. The materials used based upon actual measurement were from continuous measurement taking place every one minute, four hours a day when measuring dioxine twice a year from 2007 to 2010.

Estimation of the CO_2 emission factor: Emission factors necessary for calculation of CO_2 emissions were generated based on the contents of carbon in incinerated wastes according to the IPCC Guideline and the formula is as presented in eqn. 1.

$$EF_j = dm_j \cdot CF_j \cdot FCF_j \cdot OF_j \cdot 44/12 \qquad (1)$$

dm_j stands for the contents of dry materials (%) in j as a component of MSW incinerated while CF_j refers to the ratio of carbon (%) in dry materials of j as a component. FCF_j stands for the ratio of fossil carbon (%) in the total amount of carbon in j as a component while OF_j refers to oxidation quotient (%) and 44/12 is CO_2 conversion coefficient against carbon. To estimate emission factors, characteristic materials such as components in wastes handled in the subject incineration facilities, contents of dry materials and the ratio of carbon were studied.

Estimation of the CO_2 emission: CO_2 emission was calculated based on estimation of the amount of wastes incinerated (weight of wet matters) in consideration of materials on the level of activities of wastes coming from municipal solid wastes composition, contents of dry materials, total contents of carbon, fossil carbon fraction and oxidation factors. General methods used to calculated CO_2 emission from incineration were based on the estimate of contents of fossil carbon in wastes burned. The value is multiplied by oxidation factor and the result (amount of fossil carbon oxidized) is converted to CO_2. The material on activities refers to the amount of wastes placed in the incinerator while the emission factor is based on the contents of carbon oxidized in wastes coming from fossil fuels. Related materials cover the composition and amount of wastes, contents of dry materials, total amount of carbon, fossil carbon fraction and oxidation factor. Tiers that can be applied for estimation of CO_2 emission from incineration of wastes will be distinguished based on how differently the total amount of wastes, emission factors and variables change according to basic value (Tier 1), country-specific characteristic value (Tier 2a, Tier 2b) and facility-specific characteristic value (Tier 3)[6].

In the study, the analysis of CO_2 emission was based on a comparative analysis of emission based on Tier 2a applying the emission factor presented in the 2006 IPCC Guideline and the emission estimated based on the Tier 3 using the characteristic emission factor. As for the calculation, the CO_2 emission formula (j: component of wastes) based on the municipal solid wastes composition for more accurate estimation than the method (i: type of wastes incinerated) based on the total amount of wastes incinerator as presented in the guideline and the formula is as presented in eqn. 2.

$$CO_2 \text{ Emissions (Gg/yr)} = MSW \cdot \Sigma(WF_j \cdot dm_j \cdot CF_j \cdot FCF_j \cdot OF_j) \cdot 44/12 \qquad (2)$$

CO_2 Emissions = CO_2 emissions in inventory year (Gg/yr); MSW = total amount of municipal solid waste as wet weight incinerated (Gg/yr); WF_j = fraction of waste type/material of component j in the MSW(as wet weight incinerated); dm_j = dry matter content in the component j of the MSW incinerated (fraction); CF_j = fraction of carbon in the dry matter (*i.e.*, carbon content) of component j; FCF_j = fraction of fossil carbon in the total carbon of component j; OF_j = oxidation factor, (fraction); 44/12 = conversion factor from C to CO_2; j = component of the MSW incinerated such as paper, textiles, food waste, wood, plastics, other inert waste.

In this study, in order to compare Tier 2a with Tier 3, activities of incineration facilities were applied to MSW and WF_j. As for the ratio of dry contents in wastes (dm_j) and the ratio of carbon in dry materials (CF_j), in Tier 2a, the IPCC characteristic value was used and in Tier 3, the independently analyzed value was used. The ratio of fossil carbon in total amount of carbon (FCF_j) was based on the characteristic value of the IPCC Guideline. As for the oxidization rate (OF_j), well-designed incineration facilities in general terms and engineering point of view provide oxidization rates as high as 100 %, thus 100 % of oxidization was applied[7].

RESULTS AND DISCUSSION

CO_2 emission concentration and amount based on actual measurement: To measure CO_2 concentration, CO_2 concentration and flux were continuously measured every one minute for 4 h a day, twice a year from 2007 to 2010 from a chimney of the subject incineration facility. Generally, CO_2 emission concentration in incineration facilities for daily wastes will be almost consistent without changes to the conditions of incineration. So it tends to have a consistent concentration range almost without changes in concentration actually measured. Fig. 1 shows actually measured concentration of CO_2 emitted from a chimney of incineration facilities.

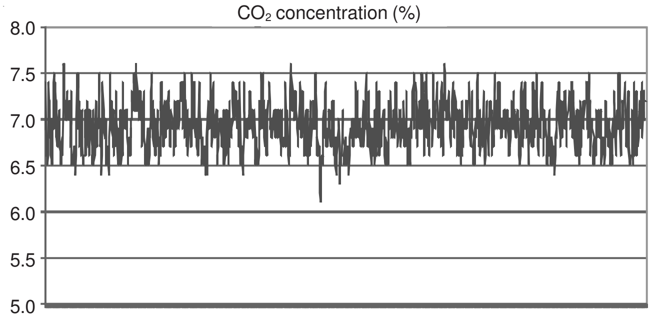

Fig. 1. Trend of actual CO_2 concentration measured in the object MSW incineration

CO_2 concentration was consistent around 6.1-7.6 % (standard conditions) and the average concentration over the measurement period was 6.96 %. CO_2 emission calculated from the actually measured average CO_2 concentration (%) is as shown in Table-2. The calculation reflected the flux of emissions, length of time of incineration and incineration temperature. The difference in CO_2 emissions, occurs based on changes of emitted flux according to the amount of wastes incinerated.

CO_2 emission concentration and amount based on the IPCC guideline

Composition of wastes: To enable accurate and reliable estimation of national greenhouse gas emission, emission factors and activities based on the plant-specific materials of unit incinerators shall be applied. The total emission of CO_2 based on incineration of wastes will be based on the addition of CO_2 emissions from all facilities. Hence, if detailed and concrete emission factors by incineration facilities are applied, the accurate estimation at the level of Tier 3 will become possible. This study analyzed properties of wastes necessary to estimate CO_2 emission from wastes incinerators, contents of dry materials and the carbon ratio. Samples of wastes for wastes properties analyses were based on the collection of homogenized wastes introduced to the wastes storing tanks while the analytic test was based on "the method of wastes processing". The composition of wastes treated in the subject incineration facilities and the composition of daily wastes in East Asia provided in the 2006 IPCC Guideline are as shown in Table-3.

Comparing with the composition in East Asia provided in the IPCC guideline, food wastes take up 26.2 %, which is high while food wastes treated in the subject incineration facilities amounted to 22.4 % in 2007, 21.3 % in 2008, 15.0 % in 2009 and 15.2 % in 2010, which is relatively low. This can be understood that the ratio of wastes treated in incinerators has fallen as the reuse increases from the quantity-based system for foodstuff in 2005[8].

Ratios of dry materials and carbon: Generally, the contents of moisture in wastes are high so it is important to decide the contents of dry materials in wastes. Among wastes incinerated, paper, food and wooden materials cover degradable organic carbon which can be dissolved with biological materials while wastes of textiles, plastic and rubber are non-biological and cover carbon as fossil fuel among daily wastes. The total amount of carbon among wastes incinerated comes from the addition of non-biological and biological materials. In order to estimate incineration-led CO_2 emission, it is necessary to distinguish the contents of non-biological carbon related to fossil fuels in incinerated wastes from the contents of biological carbon.

TABLE-2
ACTUAL EMISSIONS CONCENTRATION AND FLOW RATE BY STACK IN THE FILED

Item	Year				
	2007	2008	2009	2010	Average
CO_2 concentration (%)	6.50	7.04	7.10	6.87	6.88
Flow (Sm^3/h)	48,554	51,549	55,381	58,082	53,392
Operating time (hr/yr)	7,776	8,040	8,136	7,848	7,950
Temperature of exhaust emission (°C)	158	160	163	158	160
CO_2 emission (tCO_2eq/yr)	30,534	35,262	39,014	40,267	36,269

TABLE-3
MSW COMPOSITION DATA BY PERCENT (%) IN THIS STUDY INCINERATOR AND EASTERN ASIA DEFAULTS

Waste composition	Plant-specific					IPCC guideline
	2007	2008	2009	2010	Ave.	Eastern Asia
Paper	26.6	26.4	31.5	33.9	29.6	18.8
Textiles	9.0	8.7	6.2	7.3	7.8	3.5
Food waste	22.4	21.3	15.0	15.2	18.5	26.2
Wood	8.8	9.0	8.7	7.9	8.6	3.5
Plastic	28.2	29.1	32.3	29.2	29.7	14.3
Other	5.0	5.5	6.3	6.5	5.8	33.7

* Source: IPCC Guidelines for national greenhouse gas inventories. VOL5-2. Ch2

The contents of dry materials (%) and the total amount of carbon in dry wastes (%) analyzed are shown in Table-4. Based on the results, as for the contents of dry materials, paper took up 79 %, followed by textiles (72 %), wooden materials (85 %), plastic materials (98 %) and finally, food (33 %). Based on the contents of dry materials presented in the IPCC guideline, paper took up 90 %, followed by textiles (80 %), wooden materials (85 %), plastic materials (100 %) and finally, food (40 %). In both cases, food took up the lowest ratio. The latter case provides higher ratios than the results from this study. The total carbon contents in dry wastes were 69 % (plastic materials) 48 % (wooden materials), 48 % (textiles), 44 % (food) and 39 % (paper). Compared with the IPCC Guideline, the carbon contents tended to be lower except for food.

Estimation of CO_2 emission: CO_2 emission (Tier 2a) estimated based on the emission factor provided in the IPCC Guideline for analysis of CO_2 emission from MSW incineration facilities was compared against the estimation (Tier 3) coming from the emission factor and activities based on the plant-specific materials applied in this study.

CO_2 emissions from the MSW incineration facilities based on the IPCC guideline as well as estimates based on the Tier 2a and the Tier 3 methods are presented in Table-5.

As for the contents of dry materials and the ratio of carbon, the basic value provided in the IPCC guideline and the plant-specific value were applied. As for the ratio of fossil carbon among the amount of carbon by properties, the basic values in the IPCC guideline covering paper (1 %), textile (20 %), food and wooden materials (0 %), rubber (20 %) and plastic materials (100 %) were applied. As for the oxidation factor, 100 % was applied to estimate emissions by waste composition.

CO_2 emission based on the Tier 2a of the subject MSW incineration facility was 24,923 tCO_2eq/yr in 2007, 25,205 tCO_2eq/yr in 2008, 25,572 tCO_2eq/yr in 2009 and 25,540 tCO_2eq/yr in 2010. CO_2 emission based on the Tier 3 method was 41,241 tCO_2eq/yr in 2007, 42968 tCO_2eq/yr in 2008, 47,874 tCO_2eq/yr in 2009 and 43,520 tCO_2eq/yr in 2010.

CO_2 emission based on the Tier 2a method was between 24,923 and 25,540 tCO_2eq/yr while that based on the Tier 3 method was between 41,241 and 43,520 tCO_2eq/yr. Based on the Tier 2a method, the average CO_2 emission was 25,310 tCO_2eq/yr while that based on the Tier 3 method was 43,901 tCO_2eq/yr, meaning that the former was underestimated compared to the latter.

The significantly the estimated CO_2 emission based on the Tier 2a method using the basic value in the IPCC guideline compared against the Tier 3 method using the plant-specific value comes from the difference in composition of wastes, contents of dry materials and contents of carbon. The estimation tells that the Tier 2a method has uncertainty of measurement that is lower than that from the Tier 3 method and that CO_2 emission from textiles and plastic materials show greater differences.

CO_2 emission based on actual measurement, the Tier 2a-led theoretical value based on the IPCC guideline and CO_2 emission based on the Tier 3 method are provided in Fig. 2. Fig. 2 shows a great difference between the actually measured value and the emission provided in the IPCC guideline. Comparing with the average CO_2 emission based on actual measurement, 36,269CO_2eq/yr, the estimate based on the Tier 2a method is 25,310CO_2eq/yr, 43% valuated than actually measured value while the estimate based on the Tier 3 method is 43,901CO_2eq/yr, 21% overestimated based on the value from actual measurement[9].

The difference comes from the fact that the estimate from Tier 2a comes from the basic value in the IPCC guideline. The difference between the estimate from Tier 3 applying plant-specific materials and the value from actual measurement comes from the consideration of variables affecting contents of carbon and oxidization factors.

TABLE-4
DEFAULT DRY MATTER CONTENT, TOTAL CARBON CONTENT AND FOSSIL CARBON FRACTION OF DIFFERENT MSW COMPONENTS

Waste composition	Plant-specific		IPCC guideline (2006)	
	Dry matter content in % of wet weight	Total carbon content in % of dry weight	Dry matter content in % of wet weight	Total carbon content in % of dry weight
Paper	79	39	90	46
Textiles	72	48	80	50
Food waste	33	44	40	38
Wood	85	48	85	50
Plastic	98	69	100	75
Other	87	2	90	3

*Source: IPCC Guidelines for national greenhouse gas inventories. VOL5-2. Ch2

TABLE-5
THEORETICAL CO_2 EMISSIONS OF IPCC CALCULATED ACTIVITY DATA IN THE FIELD BY Tier 2a AND Tier 3

Waste composition	Tier 2a					Tier 3				
	2007	2008	2009	2010	Ave.	2007	2008	2009	2010	Ave.
Paper	162	164	166	166	164	170	171	206	222	192
Textiles	582	588	597	596	591	1,290	1,258	914	1,069	1,132
Food waste	–	–	–	–	–	–	–	–	–	–
Wood	–	–	–	–	–	–	–	–	–	–
Plastic	22,288	22,541	22,869	22,840	22,634	39,601	41,341	46,520	41,990	42,363
Other	1,891	1,912	1,940	1,938	1,920	181	199	233	239	213
Total	24,923	25,205	25,572	25,540	25,310	41,241	42,968	47,874	43,520	43,901

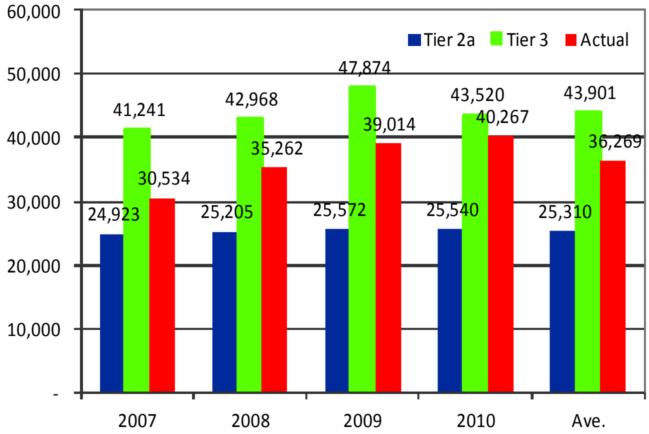

Fig. 2. Comparison of CO_2 emissions by 2006 IPCC guidline Tier 2a, Tier 3 and actual

Variables affecting the oxidation factor may greatly differ by type of installation of incineration facilities (fixed-bed, stoker, fluidized bed, rotary kiln), mode of operation (continuous, semi-continuous, batch type), size of installation and contents of carbon among incinerated materials. Hence, the subject incineration facilities are of continuous Stoker with the capacity of 200tons/day, which means that the estimate from Tier 3 that does not reflect variables such as changes in the incineration conditions and combustion efficiency must differ from the estimate based on actual measurement.

Estimation of CO_2 emission factor: CO_2 emission factors based on the comparison with the basic unit dividing CO_2 emission of the MSW incineration facilities by the amount of wastes handled are presented in Table-5. Average basic unit based on the Tier 2a method is 0.44 tCO_2eq/twaste while that based on the Tier 3 method is 0.76 tCO_2eq/twaste, meaning that valuation from Tier 2a is lower than that from Tier 3. Average basic unit estimated based on actual measurement is 0.63 tCO_2eq/twaste, standing between values from Tier 2a and Tier 3.

Fig. 3 shows that as for average basic unit, emission, just like CO_2 emission, has a great difference between the actual measurement and the basic unit based on the IPCC guideline.

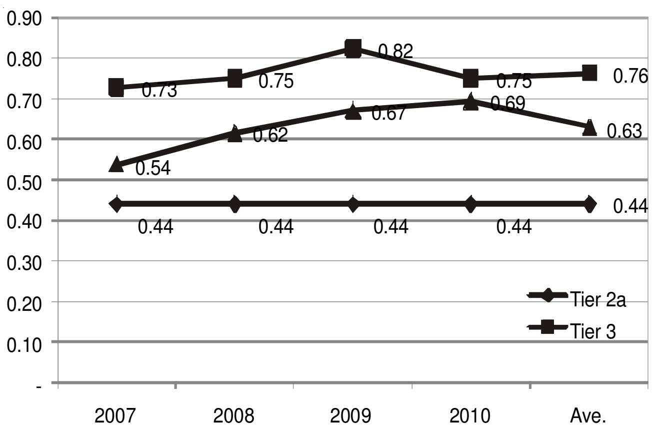

Fig 3. Comparison of CO_2 emissions factors by 2006 IPCC Guideline Tier 2a, Tier 3 and actual

Conclusion

In order to estimate CO_2 emission from the MSW incineration facilities reflecting the characteristics of the country's urban solid wastes, this study calculated the greenhouse gas emission by analyzing the contents of dry materials in wastes incinerated and the ratio of carbon in dry materials. As for CO_2 emission from the subject incineration facilities, the Tier 2a method using the basic value from the 2006 IPCC guideline 2006 IPCC guideline on emission factors, CO_2 emission provided based on the Tier 3 method using the plant-specific value and CO_2 emission based on actual measurement were comparatively analyzed. In order to derive the plant-specific emission factor, characteristic values such as the composition ratios of wastes introduced into incineration facilities, contents of dry materials, carbon ratios and oxidation factor were analyzed.

Based on the results from this study, the Tier 2a-led average CO_2 emission was 25,310 tCO_2eq/yr while the Tier 3-led average emission was 43,901 tCO_2eq/yr, meaning that the former was lower than the latter by 42%. Comparing with the average CO_2 emission, 36,269 CO_2eq/yr based on actual measurement, the estimate based on the Tier 2a method was 25,310 CO_2eq/yr, 43% lower than the actually measured estimate. The estimate based on the Tier 3 method was 43,901 CO_2eq/yr, 21% greater than the actually measured estimate. The difference comes from the use of the basic value in the IPCC guideline for Tier 2a. The difference between the estimate from the Tier 3 method using the plant-specific materials and the actually measured value comes from the consideration of variables that affect the composition ratios of wastes, contents of dry materials, contents of carbon in fossil fuels and oxidation factor[10].

The variables affecting the oxidation factor may greatly differ by the type of installation of incineration facilities (fixed-bed, stoker, fluidized bed, rotary kiln), mode of operation (continuous, semi-continuous, batch type), size of installation and the contents of carbon in incinerated materials. Hence, the subject incineration facilities are of continuous Stoker with the capacity of 200 tons/day, which means that the estimate based on the Tier 3 method that does not reflect variables such as changes in the incineration conditions and combustion efficiency must differ from the value actually measured.

For more accurate estimation of CO_2 emission coming from the country's MSW incineration facilities, the development of the country's specific emission factor reflecting the characteristics of MSW rather than the basic value provided in the 2006 IPCC Guideline will be necessary. This study is a result from application of characteristic values of single MSW incineration facilities. In future, for the development of the country's specific emission factor, studies to estimate CO_2 emission from various and develop emission factors will have to be facilitated.

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