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Comparison of GHG Emission Methods Calculated by Applying Biomass Fraction at Sewage Sludge Incinerators in Korea

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Abstract: In this study, greenhouse gas (GHG) differences due to the application of biomass content are compared at a sewage sludge incinerator. The result of the comparison shows that the differences between the methods of GHG emission estimation based on biomass fraction analysis (sewage sludge analysis and sewage sludge flue gas analysis) were not substantial. On the other hand, the GHG emission estimated from the method in this study showed a difference of 8–9 ton CO_2eq/day from the currently used method in Korea. This implies that the latter underestimates the GHG emissions because CO_2 emission was not taken into account upon estimating the GHG emission from sewage sludge. Therefore, it has been determined that, from now on, emissions due to CO_2 should be reflected in the estimation of GHG emission from sewage sludge.

Keywords: climate change; GHG estimate method; biomass fraction; sewage sludge incinerator; GHG emission

1. Introduction

Climate change due to greenhouse gas emissions can cause various events such as drought, thus there is an awareness that climate change is a global problem and countries are actively working to reduce greenhouse gases [1–3].

The Paris Agreement with its New Climate Regime was accepted in 2015 at the 21st Paris UN Climate Change Conference. The Paris Agreement has become an international law since 4 November 2016 while the New Climate Regime will be launched in 2020. It will mandate 195 participating nations of the UN Framework Convention on Climate Change to make voluntary efforts towards reducing the emission of greenhouse gas (GHG). Global Stocktake is scheduled to be performed in five-year intervals, starting from 2023, in accordance with the New Climate Regime; the participating nations will be obliged to report national GHG inventories and their progression towards the set goal of GHG reduction [4]. In order to prepare for the Global Stocktake of the New Climate Regime, the reliability of GHG inventories should be improved. Furthermore, it is important to manage GHG emissions based on the understanding of the main characteristics of each GHG emission source.

GHG emission from waste incineration in Korea amounted to 7.1 million tons CO_2eq in 2016, accounting for approximately 43% of the total GHG emission in the waste sector (16.5 million tons CO_2eq) [5]. Waste incineration is a main GHG emission source in the waste sector; hence, in preparation for the Global Stocktake of the New Climate Regime, it is crucial that the reliability of GHG inventories be enhanced and GHG emission is managed.

The IPCC Guideline suggests that CO_2 emission due to biomass should be regarded as carbon neutral and be excluded from the total CO_2 emission but reported separately. Since sewage sludge is a common biomass fuel, CO_2 emission from sewage sludge incinerators should be regarded as CO_2 originating from biomass and therefore be excluded from GHG emission estimation, while only the Non-CO_2 (N_2O, CH_4) emission should be calculated [6–8].

Previous studies have reported the possibility that sewage sludge may not be fully constituted of biomass [9–12]. In such cases, CO_2 emission should be taken into account for estimating the GHG emission from sewage sludge incinerators. Thus, to improve the reliability of estimations of GHG emission from sewage sludge incinerators, the biomass fraction of sewage sludge should be accounted for in the emission estimation.

This study set out to investigate the use of biomass fraction in estimating the GHG emission from sewage sludge incinerators and the consequent differences in the estimated emission. To this end, the biomass fraction in the sewage sludge of target incinerators and the sewage sludge flue gas were measured. Subsequently, GHG emissions were estimated and compared to those deriving from the conventional method. The method of GHG estimate used in this study is based on the methods applied in Korea's National Inventory Report and the methodology of Korea's Goal Management Guidelines. This method is based on the IPCC GPG 2000.

2. Methods

To investigate the application of biomass fraction to estimating the GHG emission from sewage sludge incinerators and the consequent differences in emission, the biomass fractions of the input sewage sludge of target incinerator and the flue gas were analyzed. The latter was collected and its concentration was analyzed for estimating CO_2 emissions, while for Non-CO_2 emissions a unique emission factor developed in Korea was used.

2.1. Selection of Objective Facilities

The objective facilities were selected among those in Gyeonggi province, where an average of 150 tons of sewage sludge is incinerated daily. The selected facilities employed fluidized-bed incineration, which is a common technology in incinerators in Korea. In order to prevent pollution, the facilities use selective non-catalytic NOx reduction for removing nitrogen oxides, bag filters for removing dust, and semi-dry reactors and wet scrubbers. The samples of sewage sludge and its flue gas were collected during the winter period between January and March 2015.

2.2. Analysis of Biomass Fraction

The standard methods for analyzing biomass fraction include ASTM D 6866, DS/CEN/TS 15440, and CEN/TR 15591 [13–15]. These standards describe, respectively, the ^{14}C method, the selective dissolution method, and the balance method, as the methods to analyze the biomass fraction. Numerous previous studies have employed these methodologies to analyze biomass fraction [16–23].

To analyze the biomass fraction of sewage sludge and its flue gas, the ^{14}C method was chosen in this study from among the three methods. This method includes LSC (liquid scintillation counter), AMS (accelerator mass spectrometry), and IRMS (isotope ratio mass spectrometer).

This study used AMS for the analysis of biomass fraction as it allows trace quantities (1 g) to be analyzed and offers 105 times higher precision than general mass analysis devices [24].

2.3. Sampling of Flue Gas and Sewage Sludge at the Incinerator

The US mandatory reporting rule for greenhouse gases states that flue gas samples for analyzing the biomass fraction of waste incinerators must be measured for a consecutive 24-h period, or up to the standard set by the ASTM D 6866-08. In compliance with the rule, samples of flue gas have been collected and analyzed for 24 consecutive hours [25].

In Korea, real-time monitoring and analysis of air pollutants are performed using the Stagger Tele-monitoring System (TMS). For the collection of flue gas, an independently developed flue gas collector was installed on the TMS. The real-time air-pollutant analyzer and the system for flue gas collection are illustrated in Figure 1. The flue gas collector is constituted by: (1) a device that cools the high-temperature gas to 3 °C, to remove moisture and make the 24-h collection easier to handle; (2) a drain pump for discharging the cooled moisture; (3) an electronic mass flow meter; (4) a pump.

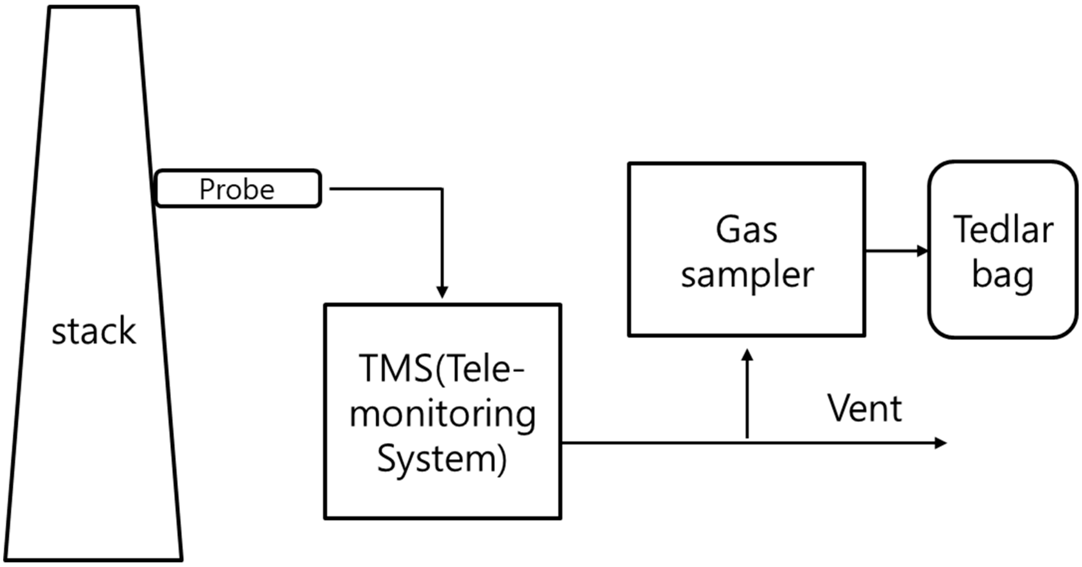

Figure 1. Schematic of the field setup for incineration gas sampling.

As shown in Figure 2, sewage sludge samples were collected from the transfer pipe during the treatment process of sludge from the hopper to the conveyor belt.

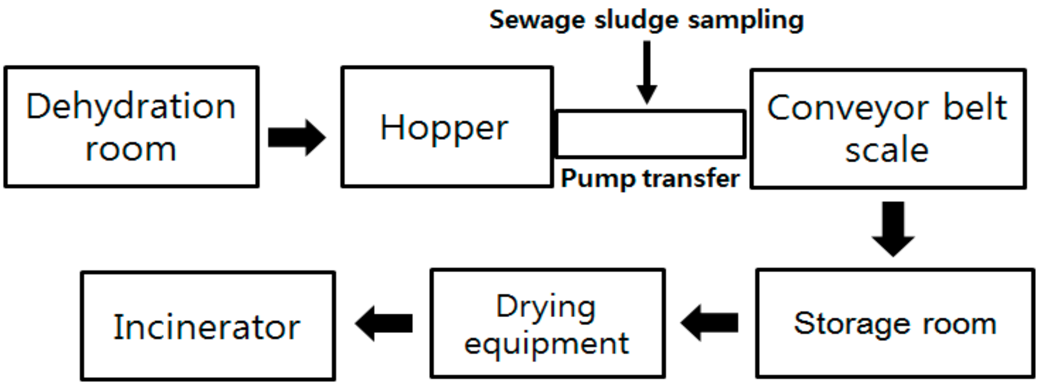

Figure 2. Schematic for Sewage sludge sampling.

2.4. Analysis of Dry Matter Content and Carbon Content in Sewage Sludge Samples

To measure the dry matter content of sewage sludge for estimating the emission from sewage sludge incinerators, the individual weight (W1i) of sewage was first measured before drying. Then, each different type of sewage was dried in a 95–105 °C drying oven for 3 to 4 h, and then placed in a desiccator until cooled to ambient temperature. Finally, the individual weight (W2i) of sewage after drying was measured.

The dry matter content was calculated from the individual weights of each different sewage type measured after drying and cooling according to Equation (1), below:

$$Dm_i = 1 - \frac{W_{2i}}{W_{1i}} \times 100 \quad (1)$$

To measure the carbon content of the dry matter in sewage sludge, an automatic elemental analyzer (AEA) was used. This is the most commonly used device for analyzing carbon, hydrogen, nitrogen, and sulfur contents. The AEA employs the dynamic flash combustion method, which oxidizes the carbon within the sewage, isolates it using a column, and uses the TCD detector for quantification.

For analyzing the carbon content, a 2 m ParaQ-X column was used, with the core temperature set to 950 °C, the TCD oven temperature set to 65 °C, the carrier gas flow rate to 140 mL/min, the oxygen flow rate to 240 mL/min, and the reference gas glow rate to 100 mL/min.

Prior to analyzing the carbon content of the sewage sludge, the reproducibility of AEA results was assessed in order to increase the validity of the analyzed values. The BBOT (2,5-bis(5-tert-butyl-benzoxazolyl) thiophene: C = 72.52%, H = 6.06%, N = 6.54%, S = 7.43%, O = 7.42%) was used as a standard sample for elemental analysis. For assessing the reproducibility, the state with unknown elemental contents and the state after the input of each elemental content of the BBOT standard sample were analyzed independently, and then compared.

The standard sample analysis returned an average carbon content of 72.52% in the BBOT standard sample and of 72.60% in the unknown state. The standard deviation of 0.09% confirmed a highly reliable reproducibility (See Table 1).

Table 1. The result of reproducibility assessment for the automatic elemental analyzer.

Classification	Carbon Content (%)	
	Standard	Unknown
1	72.52	72.49
2	72.52	72.58
3	72.52	72.65
4	72.52	72.62
5	72.52	72.64
Mean	72.52	72.60
SD	0	0.07
RSD (%)	0	0.09

2.5. Analysis of CO_2 Concentration in Industrial Waste Flue Gas

For analyzing the CO_2 concentration of the flue gas discharged from the sewage sludge incinerator, a GC-FID/Methanizer was used. The FID detector in the GC-FID/Methanizer is not sensitive to CO_2. However, attaching the methanizer allowed for the analysis of CO_2 by converting it to CH_4. A Porapak Q 80/100 column was used to isolate CO_2 from other gases. The operation conditions were as follows: temperature at sample injection area, 100 °C; temperature at the detector, 250 °C; temperature at the methanizer, 350 °C; oven temperature, 80 °C. For the flow rates, that of the carrier gas (99.999%) was set to 30 mL/min, hydrogen (99.999%) was set to 30 mL/min, and air (ZERO grade) was set to 300 mL/min. Information on the analytical conditions of the GC-FID/Methanizer for CO_2 concentration is presented in Table 2.

Table 2. Analytical conditions of GC-FID/Methanizer for CO_2 concentration.

Classification		GC/FID (DS-6200, Donam INC)
Column		Porapack Q 80/100
Carrier gas		N^2 (99.999%)
Flow	Column	30 mL/min
	H^2	30 mL/min
	Air	300 mL/min
Temperature	Oven	80 °C
	Injector	100 °C
	Methanizer	350 °C
	Detector	250 °C

To confirm the reproducibility of GC-FID results, the analysis was run five times using the standard gas with 5.1% CO_2 concentration. The resulting standard deviation of 1.14% indicated excellent reproducibility (See Table 3).

Table 3. The result of reproducibility assessment for GC-FID. (Unit: %).

Classification	Standard
1	5.20
2	5.25
3	5.14
4	5.14
5	5.10
Mean	5.17
SD	0.059
RSD (%)	1.14

2.6. GHG Emission Estimation Method at Sewage Sludge Incinerator

In this study, three methods for estimating GHG emission were used and the results were compared. The first method is the currently used method, in which CO_2 emission from sewage sludge is assumed to be 0 and only the N_2O emission is estimated. At present, the non-CO_2 component of GHG emission from waste incineration in Korea concerns only the N_2O emission, as the emission of CH_4 has been determined to be negligible. This method is used to estimate the emission of sewage sludge incineration facilities in the Korean GHG Inventory Report. The applicable emission factor is the country-specific emission factor developed in Korea, and the calculation method is shown in Equation (2).

$$E_{SSI,GHG} = SS \times EF_{N_2O} \times 10^{-6} \times 310 \quad (2)$$

where $E_{SSI,GHG}$ = GHG emission from sewage sludge incinerator, ton CO_{2eq}/day. SS = Amount of sewage sludge incineration in the target facility, ton/day. EF_{N2O} = N_2O emission factor of sewage sludge incinerator, 595 g N_2O/ton. 310 = GWP of N_2O.

The second method for estimating GHG emission is based on sewage sludge analysis, following Equation (3) shown below. The analyzed values of sewage sludge, as in the values required by the estimation of emission from domestic and industrial wastes, were based on the content of dry matter, the content of carbon in dry matter, and the fossil carbon content. In this equation, emissions are calculated on the basis of carbon content. Therefore, the conversion factor to convert carbon to carbon dioxide is considered together to estimate carbon dioxide emissions. N_2O emission was also taken into account.

$$E_{SSI,GHG} = \left[SS \times \{Dm_{ss} \times CF_{ss} \times (1 - Biomass_{ss}) \times OF_{ss}\} \times \frac{44}{12}\right] + N_2O\ emission \quad (3)$$

where $E_{SSI,GHG}$: GHG emission from sewage sludge incinerator, ton CO_{2eq}/day. *SS*: Amount of sewage sludge incineration in the target facility, ton/day. Dm_{SS}: Dry matter content of sewage sludge. CF_{SS}: Carbon content in dry matter of sewage sludge. $Biomass_{SS}$: Biomass fraction of sewage sludge. OF_{SS}: Oxidation coefficient (Apply 1). 44/12: Conversion coefficient of C to CO_2. N_2O *emission*: N_2O emission is Equation (2).

The third method of CO_2 emission estimation is based on flue gas analysis. This method estimates GHG emission by analyzing the flue gas discharged from the final outlet, following Equation (4) shown below. The GHG emission estimation involves the analysis of CO_2 concentration and of fossil carbon content in the flue gas. The method does not require categorizing the sewage type and the analyzed values of each type, which relatively simplifies the analysis procedures and offers reduced uncertainty. N_2O emission is also taken into account in this method.

$$E_{Flue\ gas,GHG} = \left[CO_2 \times Q \times \frac{44}{22.4} \times 10^{-5} \times \left(1 - Biomass_{flue\ gas}\right)\right] + N_2O\ emission \quad (4)$$

where $E_{Flue\ gas,CO_2}$: GHG emission based on flue gas analysis, ton CO_{2eq}/day. C_{CO_2}: CO_2 concentration, %. Q: Dry flow, m^3/day. $Biomass_{Fluegas}$: Biomass fraction of flue gas. *SS*: Amount of sewage sludge incineration in the target facility, ton/day. N_2O *emission*: N_2O emission is Equation (2).

3. Result and Discussion

3.1. CO_2 Concentration of Flue Gas in the Sewage Sludge Incinerator

To investigate the GHG emission from sewage sludge incinerators based on flue gas analysis, the flue gas was collected from the incinerators and its CO_2 concentration was analyzed. The results are given in Table 4 and show that CO_2 concentrations were in the range between 6.01% and 6.97% (6.54% on average).

Table 4. CO_2 concentration analysis of flue gas at sewage sludge incinerator. (Unit: %).

Sampling	Analysis	A Incinerator
1st	1	6.13
	2	6.58
	3	6.97
	4	6.89
	5	6.76
2nd	1	6.97
	2	6.56
	3	6.53
	4	6.90
	5	6.64
3rd	1	6.63
	2	6.35
	3	6.12
	4	6.01
	5	6.07
Mean		6.54
SD		0.34

3.2. Sewage Sludge Dry Matter Content and Carbon Content in the Incinerator

To estimate the contents of dry matter and carbon in the sewage sludge, the samples were collected and analyzed three times, once in each month between January and March.

Table 5 shows the dry matter content in the sewage sludge. The results show that the dry matter contents were in the range between 22.13% and 27.42% (25.61% on average).

Table 5. Dry matter content of sewage sludge. (Unit: %)

Sampling	Dry Matter Content of Sewage Sludge
1st	22.13
2nd	27.27
3rd	27.42
Mean	25.61
SD	3.01

Table 6 shows the carbon content in the sewage sludge. The results show that the carbon contents were in the range between 35.06% and 35.40% (35.23% on average).

Table 6. Carbon content of sewage sludge. (Unit: %).

Sampling	Carbon Content of Sewage Sludge
1st	35.06
2nd	35.40
3rd	35.23
Mean	35.23
SD	0.17

3.3. Biomass Fraction in the Incinerator

In this study, biomass contents of sewage sludge incineration gas and sewage sludge incineration gas samples were sampled from January to March, three times a month for a representative of minimum analytical value. Biomass content analysis was done by AMS method.

The results show that the biomass fraction in the samples of sludge was 76.92% on average, falling in the range between 76.2% and 77.3%, depending on the time of sample collection. The standard deviation of the biomass fraction in the sludge was 0.59, indicating that the differences between the samples collected at different times were not significant. The biomass fraction in the flue gas was on average 76.56%, falling in the range between 74.45% and 78.20% depending on the time of sample collection. However, the standard deviation of 1.92 indicated that the differences were not significant (See Table 7).

Table 7. Biomass fraction analysis of Sewage sludge. (Unit: %).

Sampling	Biomass Fraction of Sewage Sludge	Biomass Fraction of Sewage Sludge Flue Gas
1st	77.38	74.45
2nd	76.25	77.02
3rd	77.12	78.20
Mean	76.92	76.56
SD	0.59	1.92

The biomass fraction in the sewage sludge was shown to be approximately 0.5% higher than that in the flue gas. This difference can be considered negligible.

The results of the analyses on the sewage sludge and its flue gas showed that, in both cases, the biomass fraction was not 100%. This may be attributed to the presence of components such as the linear Alkylbenzene Sulphonate (LAS) and the 4-Nonylphenol from shampoos and detergents that were incompletely treated and remained in the sewage sludge after treatment, as suggested by Walter Giger (1984) and J. McEvoy (1985).

3.4. Comparison of Biomass Fractions in the Target Sewage Sludge Incinerators

Estimations of GHG emission by accounting for the biomass fraction in sewage sludge incinerators were compared in this study, and the result is presented in Figure 3.

As a result of the comparison of greenhouse gas emissions, the difference in greenhouse gas emissions from analysis of sewage sludge and analysis of incineration gas of sewage sludge showed no significant difference from 0.2 to 0.4 ton/day. However, the emission estimated according to the national GHG emissions in Korea was shown to be lower than that obtained by the previous two methods. This was determined to be due to the fact that any CO_2 emission from sewage sludge incinerators was assumed to be the emission of the origin biomass and regarded as 0 emissions. The results of this study showed that the biomass fraction was approximately 77% and not 100%. Thus, the emission due to CO_2 should be taken into account. Since the CO_2 emission from sewage sludge incineration was estimated at approximately 8–9 ton CO_2eq/day when N_2O emission was excluded, it is determined that the biomass fraction is an essential factor to be considered in estimating the GHG emission from sewage sludge incinerators.

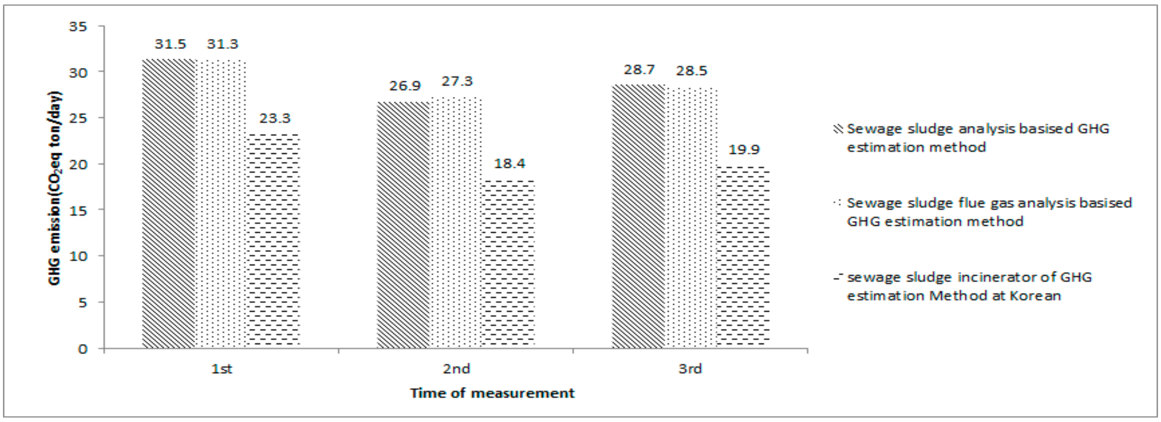

Figure 3. Greenhouse gas (GHG) emission by estimation method in this study.

4. Conclusions

In this study, the use of biomass fraction to estimate the GHG emission from sewage sludge incinerators has been investigated, and the consequent differences in emission have been discussed.

The ^{14}C method was used to analyze the biomass fractions of the input sewage sludge of target incinerators, and of the sewage sludge flue gas in the final discharge. The contents of dry matter and carbon in the sewage sludge, and the CO_2 concentration in the sewage sludge incinerators were also analyzed.

The samples of sewage sludge and its flue gas were collected three times during the period between January and March 2015, with the sample collection time being identical for all samples.

The result of biomass fraction analysis showed that the biomass fractions in the sewage sludge and in its flue gas were approximately 77%, i.e., less than 100% biomass fraction in both cases.

In this study, three methods for GHG emission estimation were used and their results compared. These methods are based on the biomass fraction analysis shown above (GHG emission estimation based on sewage sludge analysis and sewage sludge flue gas analysis), and on the conventional method used in Korea (taking into account only the N_2O emission).

The result of the comparison showed that the differences between the methods of GHG emission estimation based on biomass fraction analysis were not significant. On the other hand, the GHG emission estimated from the method in this study showed a difference of 8–9 ton CO_2eq/day from the currently used method in Korea. This implies that the latter underestimates the GHG emissions because CO_2 emission was not taken into account upon estimating the GHG emission from sewage sludge.

Therefore, it has been determined that, from now on, the emission due to CO_2 should be reflected in the estimation of GHG emissions from sewage sludge.

At present, the estimation of GHG emissions from sewage sludge incinerators in countries including Korea, Japan, and Germany, considers only the non-CO_2 GHG emission, as the CO_2 emission from sewage sludge incineration is assumed to be all of biomass origin. However, the findings of this study indicate that, to prevent the underestimation of GHG emissions from sewage sludge incinerators, CO_2 emission should also be taken into account. In this study, the biomass content of sewage sludge was analyzed for one facility, which has limitations related to the representation of the data. However, it is believed that it would be meaningful to talk about the possibility of the existence of fossil carbon content in sewage sludge through investigation of actual measurements and related studies.

Further studies on analyzing the biomass fraction of sewage sludge incinerators targeting a greater number of regions and facilities, and studies on analyzed values required for CO_2 emission estimation, are deemed necessary to provide more representative values and to enhance the reliability of GHG inventories regarding sewage sludge incinerators.

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