

Case Study of Calculating Carbon Credits for Municipal Solid Waste Incineration Power Generation

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ABSTRACT

By replacing landfilling with municipal solid waste incineration, the emission of greenhouse gases (GHGs) generated by sanitary landfilling is avoided. Simultaneously, the thermal energy generated by waste incineration is utilized for power generation, replacing an equivalent amount of electricity generated from fossil fuels, thereby reducing greenhouse gas emissions. Taking a certain municipal solid waste incineration project as an example, relevant methodologies ACM0022 and CM-072-V01 are applied, and simulated calculations of Certified Emission Reductions (CCER) are conducted through national verification. Combined with the current carbon trading prices, additional value-added benefits are calculated, providing a reference for exploring growth opportunities for waste incineration power plants and achieving carbon peak and neutrality targets for the power plants.

KEYWORDS

Municipal solid waste; Greenhouse gases; National voluntary emission reductions verification; Carbon trading.

1. INTRODUCTION

Municipal solid waste treatment facilities are essential for public environmental protection, with landfilling and incineration being mainstream processes. GHGs are generated during landfilling, with controllable but prolonged emissions, wherein methane's greenhouse gas effect is 25 times that of carbon dioxide. In comparison, waste incineration for power generation can efficiently combust waste in a shorter timeframe, converting thermal energy into steam to drive turbines for electricity generation, while emitting flue gas (including carbon dioxide). This entire process is highly controllable, effectively avoiding methane emissions from landfilling while substituting fossil fuels with thermal energy for power generation, thus achieving a dual carbon emission reduction effect of "methane emission avoidance + electricity generation substitution".

Waste incineration for power generation CCER projects, as a unique form of renewable energy generation, offer dual emission reduction effects and can be developed as CCER projects for future participation in carbon market trading. Utilizing the Life Cycle Assessment (LCA) method allows for comprehensive consideration of carbon emissions throughout the entire waste treatment process, enabling the calculation of carbon reductions for a project, region, or country, which is a more reasonable mechanism. This paper adheres to LCA and domestic and international methodologies to provide process analysis for the development of CCER projects for waste incineration power plants, offering valuable insights for project design documentation, approval, verification, and emission reduction registration.

2. LITERATURE REVIEW

2.1. Project Overview

2.1.1. Project Background

The municipal solid waste incineration power generation project processes 2,000 tons of municipal solid waste per day, constructed in two phases. The first phase has a capacity of 1,000 tons per day and is equipped with a 1,000 tons per day system (reheat steam parameters: 0.54 MPa, 154.8 °C). The project's flue gas purification process adopts the "Seven-Step Method," comprising "SNCR denitrification + semi-dry desulfurization + dry injection + activated carbon adsorption + bag dust removal + wet desulfurization + low-temperature SCR denitrification" combination scheme, surpassing the emissions standards set by the "Pollution Control Standards for Municipal Solid Waste Incineration" (GB 18485-2014) and the EU 2010/75/EU standards, meeting the emission standards for economically developed cities in the Guangdong-Hong Kong-Macao Greater Bay Area. The project's designed lower heating value (MCR) of waste is 8,500 kJ/kg.

2.1.2. Project Boundary

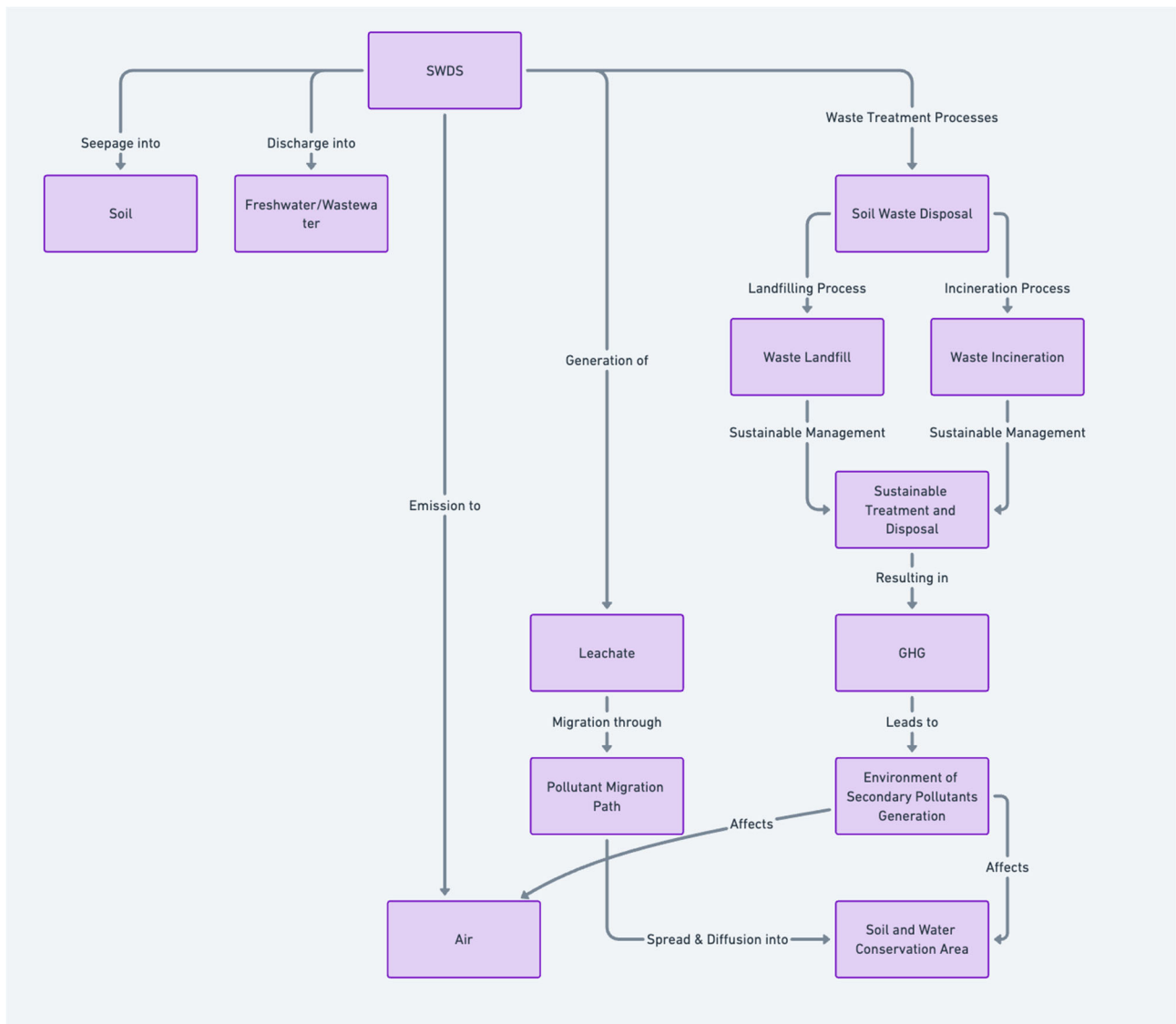


Figure 1. Project Boundary Diagram for a Waste Incineration Power Plant

According to applicable methodologies such as the IPCC 2006 National Greenhouse Gas Inventory Guidelines (2019 revised edition), ACM0022, and CM-072-V01 Multiple Choice of Waste Treatment Methods (First Edition), the spatial scope of the project boundary includes solid waste disposal sites (SWDS) processing waste below the baseline, anaerobic ponds or sludge pools treating organic wastewater within the baseline, and alternative waste treatment sites. The project boundary also encompasses on-site electricity or heat production and usage, on-site fuel usage, and wastewater treatment plants processing by-products of alternative waste treatment methods. The project boundary excludes facilities for waste collection and transportation.

The project is a municipal solid waste incineration power generation project without heating involvement. The spatial scope of the project boundary includes SWDS processing waste below the baseline, the site of the municipal solid waste incineration plant, on-site electricity production and usage, and on-site fuel usage. For situations where the project supplies electricity to the grid, the spatial scope of the project boundary also includes all power plants connected to the power system where the project's power plant is located. The schematic diagram of the project boundary is shown in Figure 1.

2.1.3. Crediting Period

The project's emission reductions adopt a fixed crediting period of 10 years, spanning from January 1, 2025, to December 31, 2034, inclusive of the first and last two days.

2.2. Project Emission Reductions

2.2.1. Baseline Emissions

Following methodology CM-072-V01, the most reasonable baseline scenario for the project is determined using the latest version of the "Baseline Scenario Identification and Additionality Demonstration Tool" by the Executive Board of the Clean Development Mechanism [7].

The baseline emissions of the project include methane baseline emissions from the SWDS, methane baseline emissions from the anaerobic treatment process of sludge in open anaerobic ponds in the absence of project activities, baseline emissions related to energy production, and baseline emissions associated with natural gas usage.

The baseline emissions are determined by the following equation:

$$BE_y = \sum_t (BE_{CH_4, t, y} + BE_{WW, t, y} + BE_{EN, t, y} + BE_{NG, t, y}) \times DF_{RATE, y, y} \quad (1)$$

$$DF_{RATE, t, y} = \begin{cases} 1 - RATE_{compliance, t, y}, & RATE_{compliance, t, y} < 0.5 \\ 0, & RATE_{compliance, t, y} \geq 0.5 \end{cases} \quad (2)$$

In the equation:

BE_y: Baseline emissions for year y, in tCO₂e;

BE_{CH₄, t, y}: Methane baseline emissions from SWDS for year y, in tCO₂e;

BE_{WW, t, y}: Methane baseline emissions from anaerobic treatment of sludge in open anaerobic ponds in the absence of project activities for year y, in tCO₂e;

BE_{EN, t, y}: Baseline emissions related to energy production for year y, in tCO₂e;

BENG, t, y: Baseline emissions associated with natural gas usage for year y, in tCO₂e;
 DFRATE, y, y: Reduction factor considering RATEcompliance, t, y;
 RATEcompliance, t, y: Compliance rate of mandatory waste treatment alternative t enforced in year y;
 t: Type of waste treatment alternative.

2.2.2. Baseline Methane

Emissions from SWDS The baseline methane emissions from SWDS are determined using the latest version of the "Emission Calculation Tool for Solid Waste Disposal Sites" by the Executive Board of the Clean Development Mechanism [8].

$$BE_{CH_4,t,y} = BE_{CH_4,SWDS,y} = \varphi_y \times (1 - f_y) \times GWP_{CH_4} \times (1 - OX) \times \frac{16}{12} \times F \times DOC_{f,y} \times MCF_y \times \sum_{x=1}^y \sum_j W_{j,x} \times DOC_j \times e^{-k_j(y-x)} \times (1 - e^{-k_j}) \quad (3)$$

In the equation:

BECH₄, t, y: Methane baseline emissions from SWDS for year y, in tCO₂e;
 y: Correction factor for year y;
 f_y: Proportion of methane collected and ignited or otherwise treated in landfill gas for year y;
 GWPCH₄: Global warming potential of methane;
 OX: Oxidation factor;
 F: Proportion of methane in landfill gas, Methane Correction Factor (MCF_y);
 DOC_f, y: Content of degradable organic carbon;
 MCF_y: Methane correction factor for year y;
 W_j, x: Quantity of organic waste type j disposed in the landfill by the proposed project in year x, in t;
 DOC_j: Mass fraction of degradable organic carbon in waste type j;
 k_j: Degradation rate of waste type j;
 j: Waste type;
 x: Year within the crediting period: x ranges from the first year of the crediting period (x=1) to the year of avoided emissions calculation (x=y);
 y: Year for methane emissions calculation.

2.2.3. Baseline Emissions from Energy

Production The baseline emissions from separate electricity generation (BEEC, y) must be determined using the latest version of the "Tool for Calculating Baseline, Project and/or Leakage Emissions from Electricity Consumption" by the Executive Board of the Clean Development Mechanism.

$$BE_{EC,y} = \sum_k EC_{BL,k,y} \times EF_{EL,k,y} \times (1 + TDL_{k,y}) \quad (4)$$

In the equation:

$BE_{EC,y}$: Baseline emissions associated with electricity generation for year y , in tCO_2e ;

$EC_{BL,k,y}$: Electricity generated by waste treatment method t in year y and input into the grid or used to replace fossil fuel only for electricity generation and/or cogeneration in self-contained power plants, in MWh;

$EF_{EL,k,y}$: Emission factor corresponding to the electricity replaced by the proposed project in year y , in tCO_2/MWh ;

$TDL_{k,y}$: Average power transmission loss for the proposed project in year y .

The project's annual grid-connected electricity is 175,470 MWh, with a baseline emission factor of 0.50885 tCO_2e/MWh for the power grid in southern China, and an average power transmission loss of 0%.

Therefore, the annual baseline emissions from separate electricity generation can be calculated by the following equation:

$$BE_{EC,y} = 175\,470 \times 0.508\,85 \times (1 + 0\%) = 89\,288\,tCO_2e \quad (5)$$

3. PROJECT EMISSIONS

The calculation of emissions for each alternative waste treatment project implemented in year y is as follows:

$$PE_y = PE_{COMP,y} + PE_{AD,y} + PE_{GAS,y} + PE_{RDF_SB,y} + PE_{INC,y} \quad (6)$$

In the equation:

PE_y : Project emissions for year y , in tCO_2e ;

$PE_{COMP,y}$: Project emissions generated from composting or co-composting in year y , in tCO_2e ;

$PE_{AD,y}$: Project emissions generated from anaerobic digestion and biogas combustion in year y , in tCO_2e ;

$PE_{GAS,y}$: Project emissions generated from gasification in year y , in tCO_2e ;

$PE_{RDF_SB,y}$: Project emissions related to RDF/SB in year y , in tCO_2e ;

$PE_{INC,y}$: Project emissions generated from incineration in year y , in tCO_2e .

The proposed project activities do not include composting or co-composting, anaerobic digestion, gasification, or mechanical or thermal production of RDF/SB, thus only involving project emissions generated from incineration.

Project emissions generated from incineration include emissions from combustion within the project boundary. If associated with the incineration process, project emissions also consider electricity consumption, fossil fuel consumption, and wastewater treatment. Therefore, the method for determining project emissions is as follows:

$$PE_{INC, y} = PE_{COM, INC, y} + PE_{EC, INC, y} + PE_{FC, INC, y} + PE_{ww, INC, y} \quad (7)$$

In the equation:

$PE_{INC, y}$: Project emissions generated from incineration in year y, in tCO₂e;

$PE_{COM, INC, y}$: Project emissions generated from combustion of fossil fuels associated with incineration within the project boundary in year y, in tCO₂e;

$PE_{EC, INC, y}$: Project emissions generated from electricity consumption associated with incineration in year y, in tCO₂e;

$PE_{FC, INC, y}$: Project emissions generated from fossil fuel consumption associated with incineration in year y, in tCO₂e;

$PE_{ww, INC, y}$: Project emissions generated from wastewater treatment processes associated with incineration in year y, in tCO₂e.

3.1. Project Emissions Generated from Electricity Consumption.

Generated from Electricity Consumption $PE_{EC, INC, y}$ is determined using the "Tool for Calculating Baseline, Project and/or Leakage Emissions from Electricity Consumption", where $PE_{EC, INC, y} = PE_{EC, t, y}$, with the waste treatment method t being incineration.

$$PE_{EC, INC, y} = PE_{EC, t, y} = \sum_j EC_{PJ, j, y} \times EF_{EL, j, y} \times (1 + TDL_{j, y}) \quad (8)$$

In the equation:

$PE_{EC, t, y}$: Project emissions generated from electricity consumption in year y, in tCO₂e;

$EC_{PJ, j, y}$: Electricity consumed by waste treatment method t from on-site fossil fuel power plants or from the grid in year y, in MWh;

$EF_{EL, j, y}$: Emission factor corresponding to the electricity replaced by the proposed project in year y, in tCO₂/MWh;

$TDL_{j, y}$: Average power transmission loss for the proposed project in year y.

As the electricity consumption of the proposed project is self-generated, $PE_{EC, INC, y} = 0$ tCO₂e.

3.2. Project Emissions Generated from Fossil Fuel

Consumption $PE_{FC, INC, y}$ is determined using the "Tool for Calculating CO₂ Emissions from Fossil Fuel Combustion" where $PE_{FC, INC, y} = PE_{FC, t, y}$, with the waste treatment method t being incineration.

$$PE_{FC,t,y} = PE_{FC,j,y} = \sum_i FC_{i,j,y} \times COEF_{i,y} \quad (9)$$

In the equation:

$PE_{FC,t,y}$: Project emissions generated from fossil fuel consumption, in tCO₂e;

$FC_{i,j,y}$: Consumption of fossil fuel i, in t or m³/a;

$COEF_{i,y}$: Emission factor for fossil fuel i, in tCO₂/t or tCO₂/m³;

i: Type of fossil fuel.

The emission factor for fossil fuel $COEF_{i,y}$ can be calculated as follows:

$$COEF_{i,y} = NCV_{i,y} \times EFCO_{2,i,y} \quad (10)$$

Where:

$COEF_{i,y}$: Emission factor for fossil fuel i, in tCO₂/t or tCO₂/m³;

$NCV_{i,y}$: Average heating value of fossil fuel i, in GJ/t or GJ/m³;

$EFCO_{2,i,y}$: Average emission coefficient of fossil fuel i, in tCO₂/GJ.

The proposed project consumes 120 tons of diesel annually. According to the IPCC National Greenhouse Gas Inventory Guidelines, the $NCV_{i,y}$ for diesel is 42.652 GJ/t, and $EFCO_{2,i,y}$ is 74.1×10^{-3} tCO₂/GJ. Therefore, the project emissions generated from fossil fuel consumption are:

$$PE_{FC,t,y} = 120 \times 42.652 \times 74.1 \times 10^{-3} = 379 \text{ tCO}_2\text{e}. \quad (11)$$

3.3. Project Emissions Generated from Combustion Within the Project Boundary

This process is unrelated to flares or methane combustion chambers. Emissions consist of carbon dioxide and small amounts of methane and nitrous oxide, as shown below:

$$PE_{COM,c,y} = PE_{COM_CO_2,i,y} + PE_{COM_CH_4,N_2O,c,y} \quad (12)$$

Where:

$PE_{COM,c,y}$: Project emissions generated from combustion within combustion chamber c in year y, in tCO₂e;

$PE_{COM_CO_2,i,y}$: CO₂ project emissions generated from combustion within combustion chamber c in year y, in tCO₂e;

$PE_{COM_CH_4,N_2O,c,y}$: CH₄ and N₂O project emissions generated from combustion within combustion chamber c in year y, in tCO₂e;

c: Combustion chamber used in project activity: incinerator.

3.3.1. Project Emissions of CO2 Generated from Combustion

Within the Project Boundary Methodologies provide three options for calculating $PE_{COM_CO_2, i, y}$. The proposed project selects "Option 1: Included in the Waste Type Section of Waste" for calculation, with the method as follows:

$$PE_{COM_CO_2, c, y} = EFF_{COM, c, y} \times \frac{44}{12} \times \sum_j Q_{j, c, y} \times FCC_{j, y} \times FFC_{j, y} \quad (13)$$

In the equation:

$PE_{COM_CO_2, c, y}$: CO₂ project emissions generated from combustion within combustion chamber c in year y, in tCO_{2e};

$EFF_{COM, c, y}$: Combustion efficiency of combustion chamber c in year y;

$Q_{j, c, y}$: Amount of fresh waste type j supplied to combustion chamber c in year y, in tons;

$FCC_{j, y}$: Total carbon content ratio in waste type j in year y, in tC/t;

$FFC_{j, y}$: Fossil carbon in total carbon content of waste type j in year y.

$EFF_{COM, c, y}$: Combustion efficiency of combustion chamber c in year y;

44/12: Conversion factor, tCO₂/tC;

c: Combustion chamber used in the project activity - incinerator;

j: Type of waste. The project emissions of CO₂ generated from combustion within the project boundary amount to 70,237 tCO_{2e}, as shown in Table 1.

Table 1. Project Emissions from Combustion within Boundary

Waste Type	Mass $Q_{j, c, y}$ y (t)	Dry Weight Ratio	$FCC_{j, y}$ y (%)	$FFC_{j, y}$ y (%)	$EFF_{COM, c, y}$	$PE_{COM_CO_2, c, y}$ y (t)
Paper/Cardboard	31,280.50	0.9	50	5	1	2,867
Textiles	11,351.50	0.8	50	50	1	10,406
Food Waste	201,480	0.4	50	0	1	0
Wood	19,418	0.85	54	0	1	0
Garden & Park Waste	24,090	0.4	55	0	1	0
Toilet Paper	0	0.4	90	10	1	0
Rubber & Leather	9,964.50	0.84	67	20	1	4,896
Plastics	13,614.50	1	85	100	1	42,432
Metals	511	1	NA	NA	1	0
Glass	730	1	NA	NA	1	0
Others (Inert Waste)	52,560	0.9	5	100	1	9,636

3.3.2. Project Boundary Combustion Generated N₂O and CH₄ Emissions

The emissions of CH₄ and N₂O generated from combustion within the project boundary are calculated using default emission factors for each ton of fresh waste incinerated:

$$PE_{COM_CH_4,N_2O,c,y} = Q_{waste,c,y} \times (EF_{N_2O,t} \times GWP_{N_2O} + EF_{CH_4,t} \times GWP_{CH_4}) \quad (14)$$

Where:

$PE_{COM_CH_4,N_2O,c,y}$: CH₄ and N₂O emissions generated from combustion within combustion chamber c in year y, in tCO_{2e};

$Q_{waste,c,y}$: Amount of fresh waste supplied to combustion chamber c in year y, in tons;

$EF_{N_2O,t}$: N₂O emission factor associated with waste treatment method t, in tN₂O/t waste;

GWP_{N_2O} : Nitrous oxide global warming potential;

$EF_{CH_4,t}$: CH₄ emission factor associated with waste treatment method t, in tCH₄/t waste;

GWP_{CH_4} : Methane global warming potential;

c: Combustion chamber used for the project activity - incinerator;

t: Type of alternative waste treatment method - incineration.

The emissions of N₂O and CH₄ generated from combustion within the project boundary are calculated as follows:

$$PE_{COM_CH_4,N_2O,c,y} = 365 \ 000 \times (1.21 \times 50 \times 10^{-6} \times 298 + 1.21 \times 0.2 \times 10^{-6} \times 25) = 6 \ 583 \ tCO_{2e} \quad (15)$$

3.4. Emissions from Wastewater Management

The project utilizes the "UASB+MBR+NF+RO" method for treating wastewater leachate. Methane generated during anaerobic treatment is entirely recovered and incinerated using a closed incinerator. Therefore, the emissions from wastewater management of the project are calculated as follows:

$$PE_{ww,t,y} = Q_{ww,y} \times P_{COD,y} \times B_0 \times MCF_{ww} \times (1 - \eta_{flare}) \times GWP_{CH_4} \quad (16)$$

Where:

$PE_{ww,t,y}$: is the methane emissions from wastewater management associated with alternative waste treatment method 2et in year y, in tCO_{2e}.

$Q_{ww,y}$: is the volume of wastewater emissions generated by the project activity in year 2ey, in m³.

$P_{COD,y}$: is the COD concentration of the wastewater emissions generated by the project activity in year 2ey, in tCOD/m³.

B_0 : is the maximum methane production capacity, indicating the maximum methane production from a given chemical oxygen demand, in tCH₄/tCOD.

MCF_{ww} : is the methane conversion factor.

GWP_{CH_4} : is the global warming potential of methane, in tCO_{2e}/tCH₄.

η_{flare} : is the methane combustion efficiency.

The emissions from leachate of the project are calculated as:

$$PE_{ww,t,y} = 73\,260 \times 0.047 \times 0.25 \times 0.8 \times 25 \times (1 - 90\%)$$

$$= 1\,722 \text{ tCO}_2\text{e}_o \quad (17)$$

Therefore, the project emissions are:

$$PE_{INC,y} = PE_{EC,INC,y} + PE_{FC,INC,y} + PE_{COM_CO_2,c,y} + PE_{COM_CH_4,N_2O,c,y} +$$

$$PE_{ww,INC,y} = 0 + 379 + 70\,237 + 6\,583 + 1\,722 = 78\,921 \text{ tCO}_2\text{e}_o \quad (18)$$

4. LEAKAGE EMISSIONS

Leakage emissions are associated with the composting/composting process, anaerobic digestion process, and the use of RDF/SB processes output to outside the project boundary. Since the proposed project activities do not include the above scenarios, the leakage amount of the proposed project is 0 tCO_{2e}. The determination of leakage does not involve specific calculation processes or the use of parameters.

5. EMISSION REDUCTION

The average annual emission reduction of the project is calculated as follows:

$$ER_y = BE_y - PE_y - LE_y \quad (19)$$

Where:

ER_y : is the emission reduction in year 2ey, in tCO_{2e}.

BE_y : is the baseline emissions in year 2ey, in tCO_{2e}.

PE_y : is the project emissions in year 2ey, in tCO_{2e}.

LE_y : is the leakage emissions in year 2ey, in tCO_{2e}.

The total emission reduction during the project calculation period is 1,227,493 tCO_{2e}, as shown in Table 2.

Table 2. Calculation of Emission Reduction During the Compliance Period

Year/Monitoring Period	Baseline Emissions	Project Emissions	Leakage	Emission Reductions
2025-01-01—2025-12-31	119,424	78,921	0	40,503
2026-01-01—2026-12-31	145,219	78,921	0	66,298
2027-01-01—2027-12-31	167,362	78,921	0	88,441
2028-01-01—2028-12-31	186,426	78,921	0	107,505
2029-01-01—2029-12-31	202,894	78,921	0	123,973
2030-01-01—2030-12-31	217,168	78,921	0	138,247
2031-01-01—2031-12-31	229,583	78,921	0	150,662
2032-01-01—2032-12-31	240,423	78,921	0	161,502
2033-01-01—2033-12-31	249,923	78,921	0	171,002
2034-01-01—2034-12-31	258,282	78,921	0	179,361
Total	2,016,703	789,210	0	1,227,493
Annual Average	201,670	78,921	0	122,749

6. CONCLUSION

The municipal solid waste incineration power generation project adopts ultra-high parameters, resulting in high efficiency and significant carbon emission reduction potential. It is projected to achieve an average annual greenhouse gas emission reduction of 122,749 tCO₂e during the first monitoring period. Calculated at an estimated CCER price of 45 CNY/t, the annual carbon emission reduction value is approximately 5.52 million CNY. Consequently, carbon trading can be conducted through the carbon market. The development of CCERs for municipal solid waste incineration power generation projects yields significant environmental, economic, and social benefits.

7. CONFLICTS OF INTEREST

Have no conflict of interest.

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None

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