Life Cycle Inventory for Landfill Treatment of Organic Materials

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Copyright and disclaimer

Important disclaimer

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1 Introduction

This report outlines the inventory development process for organic materials in landfill. This includes all materials specified in the National Inventory Report Vol. 3 (DIICCSRTE 2013). For wood in landfill an additional inventory is included based on alternative degradation assumptions published in the US (Wang, Padgett et al. 2011).

2 System boundary

The system boundary for the inventories begins with the arrival of waste at the landfill and ends with the treatment that waste and emissions from that waste. This includes the collection of methane gas and its flaring and combustion for power generation. And lime of the AusLCI guidelines a credit is provided for electricity exported from the waste of process equal to the average electricity grid in the location where the landfill operates. Importantly it should be noted that any processing of the waste prior to arrival at the landfill and transport to the landfill is not included in the inventory

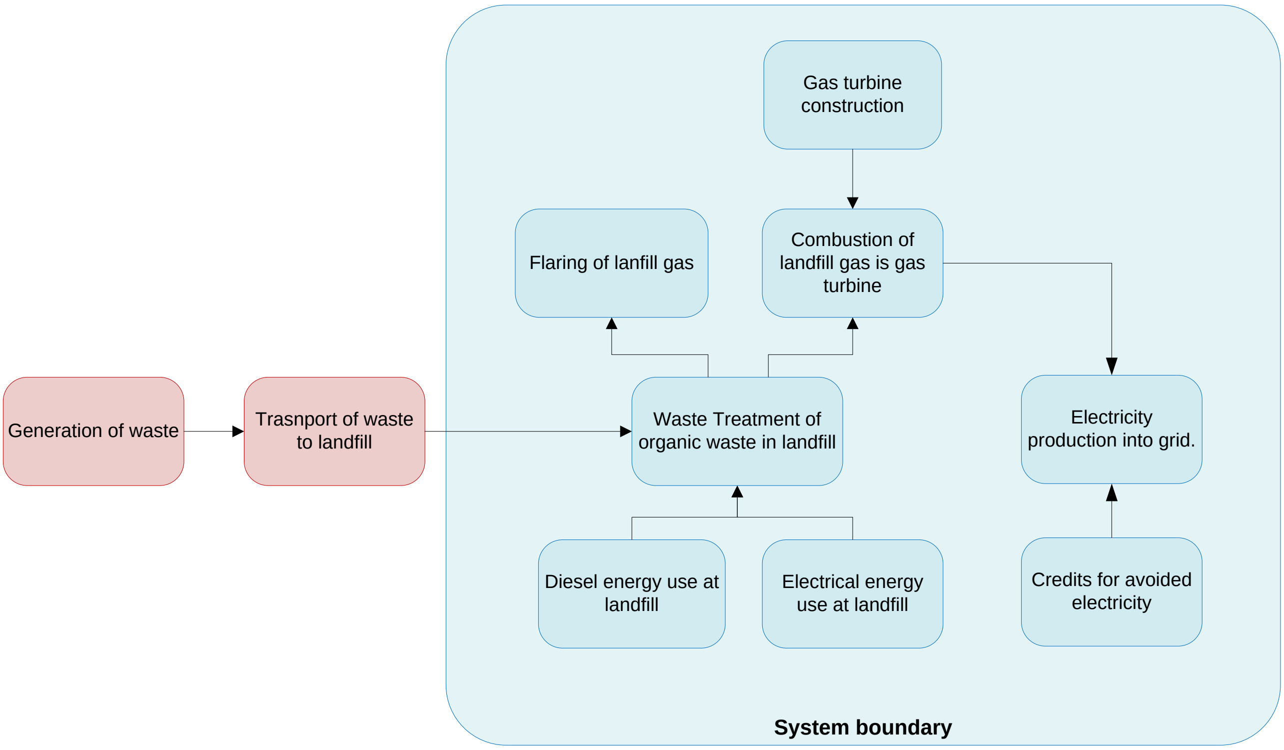


Figure 1 system boundary for landfill from organic waste inventories

3 Data Sources

Energy use data for processing and landfills has been taken from a waste management study undertaken for Eco-recycle Victoria in 2003 (Grant, James et al. 2003). Its quotes a electricity use at landfill of 0.8 kwh per tonne of waste and diesel use of 1 L per tonne of waste. The data are attributed to personal comments from landfill operators. The quantity of diesel use matches well with data presented by IVAM (IVAM University of Amsterdam 2002) and it's worth noting that there impacts of diesel and electricity use at landfill are small compared to the impacts of transport to landfill and greenhouse gas emissions from landfill from organic material.

Landfill construction and infrastructure are taken directly from Eco invent (Doka 2009).

Greenhouse gas emissions from degradation of wood in landfill are taken from the approach outlined in the National Inventory Report (DIICCSRTE 2013). This is based on a calculation of carbon dioxide and methane emissions based on the degradable organic content (DOC) of the waste, the fraction of that it degradable organic content which dissimilates in landfill (DOCf), and an assumption around the fraction of biogas generated which is methane compared to the fraction which is carbon dioxide.

Non-methanic volatile organic compounds are ashamed to be 0.2% of the landfill gas generated based on the methodology outlined in the National Inventory Report. (DIICCSRTE 2013)

3.1 Variants on DOCf

The fraction of the degradable organic content which dissimilates in landfill was initially assumed by the IPCC to be 0.5 for organic waste materials. With further research this appears to be an overestimate for materials like would and an under estimate for materials such as food. The National Inventory Report (DIICCSRTE 2013) presents a detailed discussion on the research and different values being produced and ultimately suggests a value of 0.23 for wood sent to landfill in Australia. The Department of Primary Industries in New South Wales has undertaken substantial research and suggests the number could be as low as 0.1 (Ximenes and Grant 2013). More recent work in the US suggests the value could be as low as 0.044.(Wang, Padgett et al. 2011). This later paper is used for an alternative inventory using and DOCf value of 0.044.

3.2 Landfill Gas Capture and electricity generation

The National Inventory Report suggests that landfill gas capture across Australia in 2011 was 30.5%. This value is likely to be low for the major capital cities which have been engineered landfills however in the absence of better data is has been used in the inventory. An estimate from the waste management study undertaken in 2003 in Victoria suggested that 20% of gas captured at landfill was flared with the remainder being used to produce electricity. For the National inventory the electricity which is assumed to be offset by landfill gas generation is the average Australian grid.

3.3 Coproduction of electricity with landfill

The AusLCI guidelines require processes which recycle materials or recovery energy at end of life are credited with avoided material or energy generation process which is offset, after taking account of any recycled material used in the upstream processes. Landfill gas in Australia contributes 0.3% of the electricity mix. Therefore the electricity credits provided to the landfill of wood products is multiplied 0.997 so that only the net output of electricity from landfill gas credited.

3.4 Emission from biogas combustion

Emissions from biogas production are taken from the National Greenhouse Accounts Factors (DIICCSRTE 2013) for greenhouse gas related values and from the National Pollutant Inventory from 2008 (Department of Environment and Heritage and Water 2009).

3.5 Values used for different organic fractions

While the rate of degradation in landfill is ultimately not important to the final emissions it does affect the timing of emissions both in the short and long term. The National Inventory Report (NIR) uses a first order degradation model as specified in the Tier 2 IPCC methodology (IPCC 2006) to estimate methane emissions from landfill over time. This model includes a degradation rate parameter K which is related to the half-life of organic waste fraction by the formulae $k = \ln(2)/t_{1/2}$. This parameter is sensitive to climate and moisture in the landfill and the NIR (DIICCSRTE 2013) provides rates for different materials based on different areas of Australia which are shown in Table 1.

Table 2 provides other key data for degradation calculations of each organic fraction including the DOC, DOCf and moisture content. The last parameter is not provided in the national inventory report but is needed if the inventory is to be based on waste as received with moisture.

Table 1: K values for degradation rates from different parts of Australia

	NSW Wet Temperate	VIC, WA, SA, TAS, ACT Dry Temperate	QLD, NT Moist and Wet Tropical	Average Australian
food	0.185	0.06	0.4	0.197
mixed paper	0.06	0.04	0.07	0.060
garden and green	0.1	0.05	0.17	0.104
wood and wood waste	0.03	0.02	0.035	0.030
textiles	0.06	0.04	0.07	0.060
sludge	0.185	0.06	0.4	0.197
nappies	0.04	0.04	0.07	0.052
rubber and leather	0.06	0.04	0.07	0.060
newsprint	0.06	0.04	0.07	0.060
office paper	0.06	0.04	0.07	0.060
corrugated containers	0.06	0.04	0.07	0.060
coated paper	0.06	0.04	0.07	0.060

Source:(DIICCSRTE 2013)

Table 2: Degradable organic content, DOC dissimilated and moisture content of organic waste fractions

	DOC*	DOCf values*	Moisture Content#
food	0.15	0.84	0.7
mixed paper	0.4	0.49	0.12
garden and green	0.2	0.47	0.12
wood and woodwaste	0.43	0.23	0.12
textiles	0.24	0.5	0.12+
sludge	0.05	0.5	0.8
nappies	0.24	0.5	0.6+

rubber and leather	0.39	0.5	0.12
newsprint	0.49	0.15	0.12
office paper	0.4	0.88	0.12
corrugated containers	0.47	0.45	0.12
coated paper	0.34	0.21	0.12

4 Results

Greenhouse gas emission results are provided here as a check for consistency with other data and are not intended to be used for comparative analysis. The results in Figure 2 show that the growth gas emissions are dominated by methane with a small mission of nitrous oxide and a small mission credit of fossil derived carbon dioxide from electricity offsets. Figure 3 shows that the timing of emissions for each organic fraction varies with some materials such as food degrading very rapidly and others such as corrugated containers degrading at a slower rate but after 200 years the total emissions are very similar per kilogram of waste. The high result office paper is a combination of a high DOCf value and a low moisture content which means that the dry matter content per kilogram of wet waste sent to landfill is higher than for example food waste.

Figure 2 GHG emissions by gas type from different organic fractions in landfill. Kg CO_2e per kg waste

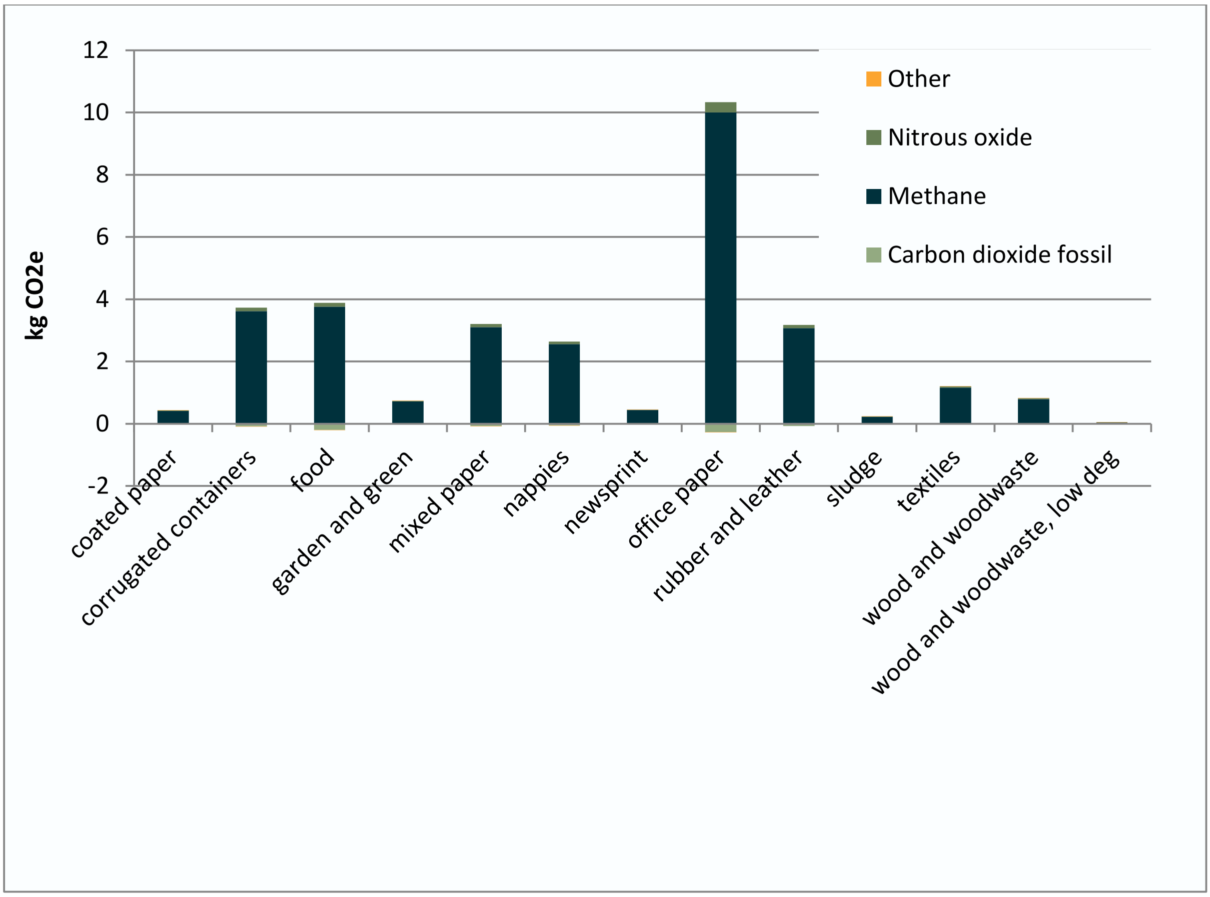
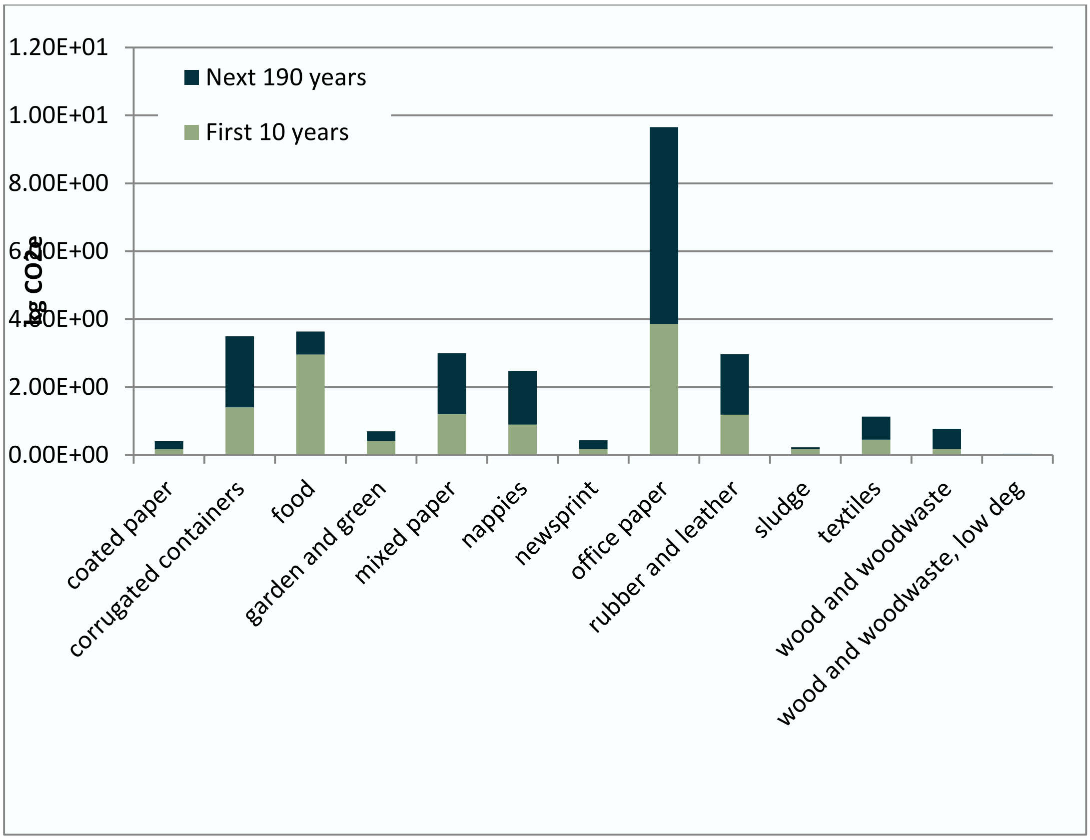


Figure 3 Timing of GHG emissions from different organic fractions in landfill. Kg CO_2e per kg waste



Source:*(DIICCSRTE 2013) #(US EPA 2006) +Author estimate

5 Inventories

Table 3 presents the basic structure of the organic material inventories. The only four numbers which vary for the different organic material types are the DOC, DOCf, the moisture content and the K value for calculating the degradation rate of the waste.

Where parameters are used in the inventory the value of the parameter is shown in square brackets. At the end of the inventory flows the input parameters are described along with any calculated parameters. Table 3 shows the inventory calculations for timber in landfill using the default landfill degradation assumptions. Table 4 shows the calculator parameters which are included in the inventory to calculate the timing of emissions using a first order degradation model as specified by IPCC tier two approach. The results from this model give slightly total methane results the calculations prescribed in the NIR. For this reason only the proportion of total methane emitted is taken from the FOD model and not the absolute value.

Table 5 shows the inventory for methane combustion and power generation.

Table 3: Waste treatment, organic material, at landfill, IPCC default

Summary data	
Status	To be reviewed
Date	06/02/2014
Record	Data entry by: Tim Grant;Telephone: 0061 408104977; E-mail: tim@lifecycles.com.au; Company: LCS; Country: AU;
Generator	Data entry by: Tim Grant;Telephone: 0061 408104977; E-mail: tim@lifecycles.com.au; Company: LCS; Country: AU;
Literature references	National Greenhouse Gas Inventory/2013/DIICCSRTE
	Life Cycle Assessment of Waste and Resource Recovery Options/2003/Grant, James
	Quantifying the greenhouse benefits of the use of wood products/2013/Ximenes
Comment Included processes: The process begins with the input of wood to landfill and includes processing of the landfill and emissions over the landfill life. Remark: Process is for the disposal of timber in landfill using the assumptions outlined in the national greenhouse gas inventory to Australia. Geography: Refers to an average production in the Australia. Technology: Average ; Time period:2012; Version: 1.0;	

Flow	Unit	Value	Distribution	SD[2]	Comment
Waste treatment, wood, at landfill, IPCC default/AU U	kg	1000			
Materials and Energy					
Electricity, low voltage, Australian/AU U	kWh	0.8	Lognormal	1.38	(4,5,4,3,1,na) Grant, James 2003
Diesel used in industrial machinery, per litre fuel/AU U	l	1	Lognormal	1.38	(4,5,4,3,1,na) Diesel usage for waste handling at the landfill site=1L/tonne waste, pers. comm, S.Middleton, Pacific Waste, NSW, 1998.
Sanitary landfill facility/CH/I U/AusSD	p	5.56E-07	Lognormal	3.09	(4,5,2,1,1,na), Based on ecoinvent value;
Emissions to air					
Methane, biogenic	t	CO2_emission [0.04122]			
Carbon dioxide, biogenic	t	CH4_Emission [0.2094]			
NMVOC, non-methane volatile organic compounds, unspecified origin	t	NMVOC_emission [0.01787]			
Final waste flows					
Waste, final, inert	t	1-(doc*docf)) [901.1]			
Waste to treatment					
Methane, combustion for power generation/AU U	t	CH4_Recovered [0.02014]			
Input parameters					
DOC		0.43	Lognormal	1.3	(4,1,1,1,1,5), DIICCSRTE 2013;
OXFactor		0.1	Lognormal	2.05	(2,3,1,1,1,5), Landfill oxidation factor based on DIICCSRTE 2013;
DOCf		0.23	Lognormal	2.05	(2,3,1,1,1,5) Fraction of DOC which degrades, DIICCSRTE 2013;
F1		0.5	Lognormal	1.22	(2,3,1,1,1,5) Fraction of landfill gas which is methane DIICCSRTE 2013;
Carbon		0.49	Lognormal	1.07	(2,1,1,1,1,na) Fraction of material which is carbon 49% from US EPA;
Rec_CH4		0.3054	Lognormal	2.05	(2,3,1,1,1,5) Fraction of Methane recovered;
Moisture_Cont		0.2	Lognormal	1.22	(2,3,1,1,1,5) Inferred from USEPA calculation between dry and wet waste calculations;
Calculated parameters					
CO2_fromCH4ox		CH4_production*21/16*OXFactor*CO2FromC			carbon dioxide from oxidation methane through the cap

CO2_Production		(DOC*DOCf*(1-F1))*(1-EF_NMVOC)*CO2FromC			Includes CO2 in biogas not captured and CO2 produced from methane oxidised through the cap of the landfill.
CH4_production		DOC*DOCf*F1*16/12			Per wet tonne
CH4_Emission		DOC*DOCf*F1*16/12*(1-Rec_CH4)*(1-OXFactor)			Per wet tonne
CH4_Recoverd		DOC*DOCf*F1*16/12*(Rec_CH4)			Methane captured
C_Stored		(Carbon-(DOC*DOCf))*(1-Moisture_Cont)			Carbon stored

Table 4 Calculator parameters used to determine the mission timing using first-order degradation FOD model

CH4BStotal		CH40to100+CH4101to200			Total emissions over the timeframe according to FOD model
CH40to10		CH4emy1+CH4emy2…+CH4emy10			Emissions first 10 years
DCa		mass_wet_waste*DOC*DOCf			Initial mass of degrading carbon
d_Cosy1		Dca*(1-exp(-MGC*(13-7)/12))			Loss of Organic Carbon in the first year. •
d_Cosy2		CcsY1*(1-exp(-MGC))			Quantity decomposable degradable organic carbon from the opening stock of carbon at the landfill lost through decay in year2 •
d_Cosy3…201		CcsY2*(1-exp(-MGC))			Quantity decomposable degradable organic carbon from the opening stock of carbon at the landfill lost through decay in year3….201
CcsY1		Dca-d_Cosy1			Organic carbon remaining after the first year •
CcsY2		Ccsy1-D_Cosy2			Quantity of decomposable degradable organic carbon accumulated in landfill at beginning of the year 2 •
CcsY3….201		Ccsy200-D_Cosy201			Quantity of decomposable degradable organic carbon accumulated in landfill at beginning of the year 3…. 201 •

CH4emy1		d_Cosy1*F1*(1-ox)*CH4FromC*iff(T0<1,1,0)*iff(TF>1,1,0)			Emission in first year
CH4emy2		d_Cosy2*F1*(1-ox)*CH4FromC*iff(T0<2,1,0)*iff(TF>2,1,0)			Methane emissions in year 2
CH4emy3….200		d_Cosy200*F1*(1-ox)*CH4FromC*iff(T0<200,1,0)*iff(TF>200,1,0)			Methane emissions in year 3 … to …200

Table 5: Methane, combustion for power generation/AU U

Summary data	
Status	To be reviewed
Date	06/02/2014
Record	Data entry by: Tim Grant;Telephone: 0061 408104977; E-mail: tim@lifecycles.com.au; Company: LCS; Country: AU;
Generator	Data entry by: Tim Grant;Telephone: 0061 408104977; E-mail: tim@lifecycles.com.au; Company: LCS; Country: AU;
Literature references	National Greenhouse Accounts Factors/2013/DIICCSRTE
	Life Cycle Assessment of Waste and Resource Recovery Options/2003/Grant, James
	Quantifying the greenhouse benefits of the use of wood products/2013/Ximenes

Comment Included processes: Process begins with the combustion of methane and ends with the generation of electricity and includes emissions from the electricity and offsets of grid electricity.
Remark: The credit for electricity generation is applied to be compliant with the AusLCI guidelines which in turn use EN 15 804 methodologies for end of life recycling and energy recovery.
Geography: Refers to an average production in the Australia.
Technology: Average
Time period: Data collected for 2012
Version: 1.0

Flow	**Unit**	**Value**	**Distribution**	**SD2**	**Comment**

Methane, combustion for power generation/AU U	kg	1			
Avoided products					
Electricity mix, Australia/AU U	kWh	KWhOffset [3.478]	Undefined	0	Based on amount of gas, efficiency of generation and allowing for fraction of gas which is flared. Also account for house load and Landfill gas accounted in the National electricity grid.
Emissions to air					
Carbon dioxide, biogenic	kg	MJ_Biogas*EF_CO2/1000 [2.464]	Undefined	0	From NIR 2009 data, Table 3.7, for all major waste gas power plants. ;
Methane, biogenic	g	MJ_Biogas*EF_CH4/1000 [10.97]	Undefined	0	From NIR 2009 data, Table 3.7, for all major waste gas power plants. ;
Dinitrogen monoxide	g	MJ_Biogas*EF_N2O [4.668]	Undefined	0	From NIR 2009 data, Table 3.7, for all major waste gas power plants. ;
Carbon monoxide, biogenic	g	MJ_Biogas*EF_CO [16360]	Undefined	0	From NIR 2009 data, Table 3.7, for all major waste gas power plants. ;
Nitrogen oxides	g	MJ_Biogas*EF_NOx [40130]	Undefined	0	From NIR 2009 data, Table 3.7, for all major waste gas power plants. ;
NMVOC, non-methane volatile organic compounds, unspecified origin	g	MJ_Biogas*EF_NMVOC [3850]	Undefined	0	From NIR 2009 data, Table 3.7, for all major waste gas power plants. ;
Sulfur dioxide	g	MJ_Biogas*EF_SO2 [110.7]	Undefined	0	From NIR 2009 data, Table 3.7, for all major waste gas power plants. ;
Cumene	mg	kWh_GEN/Biogas_to_elec*EF_Cumene [0.8723]	Undefined	0	From NPI 2009 data for 17 Australian landfill gas power plants.
Fluoride	mg	kWh_GEN/Biogas_to_elec*EF_Fluoride [0.345]	Undefined	0	From NPI 2009 data for 17 Australian landfill gas power plants.
Hydrogen chloride	mg	kWh_GEN/Biogas_to_elec*EF_HCL [4.926]	Undefined	0	From NPI 2009 data for 17 Australian landfill gas power plants.
Mercury	mg	kWh_GEN/Biogas_to_elec*EF_Mercury [0.3943]	Undefined	0	From NPI 2009 data for 17 Australian landfill gas power plants.
Particulates, < 10 um	mg	kWh_GEN/Biogas_to_elec*EF_Particulates_less10 [137.1]	Undefined	0	From NPI 2009 data for 17 Australian landfill gas power plants.
Particulates, < 2.5 um	mg	kWh_GEN/Biogas_to_elec*EF_Particulates_less25 [190.6]	Undefined	0	From NPI 2009 data for 17 Australian landfill gas power plants.

PAH, polycyclic aromatic hydrocarbons	mg	kWh_GEN/Biogas_to_elec*EF_PAH [0.1274]	Undefined	0	From NPI 2009 data for 17 Australian landfill gas power plants.
Hydrocarbons, unspecified	mg	kWh_GEN/Biogas_to_elec*EF_Hydrocarbons [437.5]	Undefined	0	From NPI 2009 data for 17 Australian landfill gas power plants.
Input parameters					
Biogas_to_elec		0.8	Lognormal	1.58	(4,3,3,3,1,na) Fraction of biogas collected which is used for electricity generation, remainder is assumed to be flared with no energy recovery. Based on Victoria in 2003 ;
GenerationEff		0.35	Undefined	0	Generation efficiency of landfill gas power generation;
House_load		0.068	Lognormal	1.05	(1,1,1,1,1,na), fraction of energy used by power station internally, inferred from ESAA 2009;
LFGinGrid		0.003	Undefined	1	Fraction of landfill gas generation already account in National Grid.
ED_Gas		48.12	Lognormal	1.05	(1,1,1,1,1,na), Assumed to be same as natural gas.
EF_CO2		51.7	Lognormal	1.07	(2,1,1,1,1,na), [kg/GJ fuel](2,1,1,1,1,na), [kg/GJ fuel] NGA factors, DIICCSRTE 2013 - based on natural gas but labelled biogenic.
EF_CH4		228	Lognormal	1.5	(2,1,1,1,1,na), [g/GJ fuel] NGA factors, DIICCSRTE 2013
EF_N2O		0.097	Lognormal	1.5	(2,1,1,1,1,na), [g/GJ fuel] NGA factors, DIICCSRTE 2013
EF_CO		340	Lognormal	5	(2,1,1,1,1,na), [g/GJ fuel] average emission of CO from main fuel, NIR 2009 data, Table 3.7, for all major landfill gas power plants.
EF_NOx		834	Lognormal	1.5	(2,1,1,1,1,na), [g/GJ fuel] average emission of NOx from main fuel, NIR 2009 data, Table 3.7, for all major landfill gas power plants.
EF_NMVOC		80	Lognormal	1.5	(2,1,1,1,1,na), [g/GJ fuel] average emission of NMVOC from main fuel, NIR 2009 data, Table 3.7, for all major landfill gas power plants.
EF_SO2		2.3	Lognormal	1.5	(2,1,1,1,1,na), [g/GJ fuel] average emission of SO2 from main fuel, NIR 2009 data, Table 3.7, for all major landfill gas power plants.
EF_Cumene		0.18645388	Lognormal	5	(2,1,1,1,1,na), mg/kWh electricity produced. From NPI 2009 data for all AU landfill gas power plants.
EF_Fluoride		0.07373778	Lognormal	5	(2,1,1,1,1,na), mg/kWh electricity produced. From NPI 2009 data for all AU landfill gas power plants.
EF_HCl		1.0528739	Lognormal	5	(2,1,1,1,1,na), mg/kWh electricity produced. From NPI 2009 data for all AU landfill gas power plants.
EF_Mercury		0.08429122	Lognormal	5	(2,1,1,1,1,na), mg/kWh electricity produced. From NPI 2009 data for all AU landfill gas power plants.
EF_Particulates_less10		29.2988547	Lognormal	2	(2,1,1,1,1,na), mg/kWh electricity produced. From NPI 2009 data for all AU landfill gas power plants.

EF_Particulates_less25		40.7462264	Lognormal	2	(2,1,1,1,1,na), mg/kWh electricity produced. From NPI 2009 data for all AU landfill gas power plants.
EF_PAH		0.02722307	Lognormal	3	(2,1,1,1,1,na), mg/kWh electricity produced. From NPI 2009 data for all AU landfill gas power plants.
EF_Hydrocarbons		93.5205748	Lognormal	3	(2,1,1,1,1,na), mg/kWh electricity produced. From NPI 2009 data for all AU landfill gas power plants.
Calculated parameters					
MJ_Biogas		ed_gas			MJs in 1 kg of Biogas
kWh_GEN		ED_gas*GenerationEff*Biogas_to_elec/3.6			kWh generated after accounting for thermal efficiency of generation plant and the fraction of landfill gas which is flared and not used for power generation.
KWhOffset		kWh_GEN*(1-House_load)*(1-LFGinGrid)			Account for electricity used in house and for landfill gas credit already implicitly accounted in National Grid.

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