# Estimating National Landfill Methane Emissions: An application of the 2006 IPCC Waste Model in Panama

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## ABSTRACT

This paper estimates methane emissions from solid waste disposal sites in Panama for years 1990-2020 using both the 2006 IPCC Waste Model spreadsheet and the default emissions estimate approach presented in the 1996 IPCC Good Practice Guidelines. The IPCC Waste Model has the ability to calculate emissions from a variety of solid waste disposal site types, taking into account country- or region-specific waste composition and climate information, and can be used with a limited amount of data. Countries with detailed data can also run the model with country-specific values. The paper discusses methane emissions from solid waste disposal, explains the differences between the two methodologies in terms of data needs, assumptions and results, describes solid waste disposal circumstances in Panama, and presents the results of this analysis. It also demonstrates the Waste Model's ability to incorporate landfill gas recovery data and to make projections. The former default method methane emissions estimates are 25.0 Gg in 1994, and range from 23.1 Gg in 1990 to a projected 37.5 Gg in 2020. The Waste Model estimates are 26.7 Gg in 1994, ranging from 24.6 Gg in 1990 to 41.6 Gg in 2020. Emissions estimates for Panama produced by the new model were, on average, 8% higher than estimates produced by the former default methodology.

## INTRODUCTION

The decay of wastes in solid waste disposal sites (SWDS) produces methane ($CH_4$), carbon dioxide ($CO_2$), and small amounts of non-methane volatile organic compounds (NMVOCs). Waste in SWDS is initially decomposed by aerobic bacteria, until oxygen is depleted. The remaining waste is broken down by anaerobic bacteria into substances such as cellulose, amino acids, and sugars, which are then fermented into the gases and short-chain organic compounds that form substrates for the growth of methanogenic bacteria. The fermentation products are then converted into stabilized organic materials and biogas consisting of approximately 50 percent $CO_2$ and 50 percent $CH_4$, by volume.

The amount of $CH_4$ generated at SWDS is determined by the quantity and composition of wastes, moisture content, pH, and waste management practices. In general, $CH_4$ production increases with higher organic content and higher moisture content in landfills. Solid waste disposal sites that create anaerobic conditions will generate the most $CH_4$. Managed sanitary landfills (where wastes decay, for the most part, under anaerobic conditions) generally have greater $CH_4$ emissions than unmanaged solid waste disposal sites (where a larger amount of waste can decay aerobically in top layers). Deeper unmanaged solid waste disposal sites have greater $CH_4$ emissions than shallow unmanaged sites.

Globally, SWDS are a significant source of anthropogenic $CH_4$ emissions. Methane is a greenhouse gas with a global warming potential of 21 times that of carbon dioxide.[1] In 2005, SWDS emitted 747.4 $MtCO_2e$, which is approximately 12% of the anthropogenic $CH_4$ emitted globally.[2] In general, over the next decade, emissions from this source are projected to decline in developed countries, remain stable in economies in transition, and rise in developing countries.[2]

Most countries account for $CH_4$ from solid waste disposal in their national greenhouse gas inventories. As established by the United Nations Framework Convention on Climate Change (UNFCCC), all parties shall "develop, periodically update, publish and make available…national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies…"[3] Non-Annex I Parties (developing countries) are initially to estimate national greenhouse gas inventories for the year 1994 or 1990, and then to produce another inventory with data from the year 2000.[4]

To ensure accuracy and comparability between inventories from different countries, the Intergovernmental Panel on Climate Change (IPCC) develops methodologies to estimate greenhouse gases from the most important anthropogenic sources of greenhouse gases within the categories of energy, industrial processes and product use, agriculture, forestry and other land use, and waste. In past IPCC guidance, the default method for $CH_4$ emissions from solid waste disposal sites allowed countries to estimate these emissions with a simple equation requiring waste disposal data only for the inventory year. An assumption of this method is that all $CH_4$ emissions are generated in the year in which the waste is disposed. In the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, the former default method for solid waste $CH_4$ emissions estimates has been replaced with a first order decay (FOD) method, which is less likely to over- or underestimate emissions from this source.[5] The FOD requires historical data, and decay rates. To make the use of this method available to countries with low data availability, the IPCC created an Excel-based spreadsheet model (IPCC Waste Model) that will facilitate FOD emissions estimates in countries where this would not have been possible before.

This paper discusses the implications of moving from the former default IPCC method to the first order decay, 2006 IPCC Waste Model to estimate CH4 emissions from SWDS. Its application to generate estimates of $CH_4$ emissions from SWDS Panama's national solid waste circumstance is presented as an example. Results from the new model are compared with results obtained with the former IPCC methodology. Examples of the use of the model to project emissions are also presented.

## APPROACH

### Model Development Background

In IPCC's *Revised 1996 IPCC Guidelines* and the *IPCC Good Practice Guidance*, the default method for estimating $CH_4$ emissions from SWDS utilized a mass-balance equation.[6,7] This method attributes all potential $CH_4$ that would be emitted from waste disposed of in a given year to that year in which the waste is disposed. This method, however, does not reflect the degradation profile of wastes over time. In reality, there is a time delay before $CH_4$ emission begins, and $CH_4$ emissions can continue to occur for several decades after waste disposal.

Methane generation from SWDS is highest the first few years after deposition and then decreases as the available carbon is consumed. The assumption in the former default method that all $CH_4$ is generated in the year in which waste is deposited creates inaccuracies in emissions estimates in situations where waste quantity, composition, and conditions are not the same every year. If waste disposal is increasing, this method will overestimate emissions.

According to IPCC guidance, emissions are to be reported for "the calendar year during which the emissions to (or removals from) the atmosphere occur."[5] The Guidelines strongly encourage the use of the FOD model, which produces more accurate emissions estimates that reflect the degradation rate of wastes in a landfill. To assist those countries that evaluated SWDS emissions with mass balance in the past and will now produce estimates using the FOD model, the IPCC developed the Waste Model, and improved default values.

**Methods and Data**

The former default method (see Equation 1) required total national municipal solid waste (MSW) generation, fraction of MSW disposed in SWDS, $CH_4$ recovery (if any), oxidation factor (if appropriate) and a $CH_4$ generation potential (the quantity of $CH_4$ that could be emitted from a unit of waste) for the inventory year. The $CH_4$ generation potential is the product of a $CH_4$ correction factor (accounts for the degree to which the waste degrades anaerobically), the degradable organic carbon (DOC) content of the waste (determined by waste composition), the fraction of the DOC that is dissimilated, and the $CH_4$ content of gas.

Equation (1) $CH_4$ emissions (Gg/yr) = [(MSWT • MSWF • L0) – R] • (1 – OX)

where

MSWT = total MSW generated (Gg/yr)
MSWF = fraction of MSW disposed at SWDS
R = recovered $CH_4$ (Gg/yr)
OX = oxidation factor (fraction)
$L_0$ = $CH_4$ generation potential (Gg $CH_4$/Gg waste)
MCF = methane correction factor
DOC = degradable organic carbon (Gg C/Gg MSW)
$DOC_F$ = fraction of DOC dissimilated
F = fraction by volume of $CH_4$ in landfill gas

The basic equation for the FOD in the IPCC Waste Model using the "bulk waste" option and a time delay is presented below (see Equation 2). This is the simplest inventory calculation performed by the model.

Equation (2) $$CH_4\ Emissions_T\ (Gg/yr) = \left[\sum_{x=S}^{T-1}\left\{MSWT_x MSWF_x L_{0,x}\left(e^{-k(T-x-1)} - e^{-k(T-x)}\right)\right\} - R\right] \bullet (1 - OX)$$

where

x = year in which waste was disposed,
S = start year of inventory calculation,
T = inventory year for which emissions are calculated, and
k = reaction constant ($yr^{-1}$).

The $CH_4$ emission estimate accounts for $CH_4$ oxidation and recovery as before, but now includes a sum of the emissions generated in the current inventory year from the waste deposited in all previous years. The model includes the delay time in $CH_4$ generation as an input parameter to the model, and adjusts the emission inventory calculations accordingly. The model also provides an option in which $CH_4$ generation can be estimated for different types of waste material; this approach requires waste disposal quantities and values of DOC and k by waste type.

The primary inputs to the 2006 IPCC Waste Model are the parameters used to calculate the $CH_4$ generation potential (i.e., the DOC in the waste, the $DOC_f$, and the MCF and the waste disposal quantities). There are three drop-down menus that set the appropriate default values and the modeling methodology. First, users select the country's region; next, users indicate whether they will be entering waste composition data for the country or bulk waste data if composition data do not exist; and then, users choose a climate (dry temperate, wet temperate, dry tropical, and moist and wet tropical). The model uses this information to select default DOC and k values for waste, a regional per capita waste generation rate, and default waste composition (if modeling by waste composition). These default values can be changed by the user.

Users also enter the start year of the calculation. Typically, fifty years of historic disposal data are needed for the FOD model to ensure that all wastes that contribute to emissions in the inventory year are included in the estimate. As such, the starting year default value is 1950.

Next, users enter information on the types of SWDS in the country by setting the percentage of wastes managed in unmanaged shallow, unmanaged deep, managed, managed semi-aerobic, and uncategorized sites. With a starting year of 1950, users must enter data or make assumptions for waste management for the past 50 years. The model calculates an annual weighted average MCF based on the selections made here.

The next required input is the amount of waste deposited in landfills. If these data are not available, the Waste Model can estimate the waste quantities from population data. The user must enter population from the starting year to the year of the estimate (or to the year of any projections); this information can be obtained from a national census. The Waste Model automatically enters regional default values for the per capita waste generation rate and the fraction of waste generated that is land disposed.

Industrial waste emissions, though not included in this analysis, can be calculated with the model. Input requirements for industrial wastes are similar to those for municipal wastes except industrial waste generation is typically correlated with gross domestic product (GDP). Due to the variability of industrial wastes in different countries, no regional default values are included for industrial wastes.

Finally, users can also enter values for oxidation and $CH_4$ recovery. The default value for these inputs is zero.

**Solid Waste Disposal in Panama**

Panama provides a good case study for the use of the Waste Model because its solid waste management practices and experience in data collection and retention is typical of many developing countries, most of which are going to produce an updated national greenhouse gas inventory for the year 2000. Panama's first national communication to the UNFCCC in 2000 included an inventory of greenhouse gas emissions and sinks for the year 1994, but documentation for that inventory is no longer available.[8] Panama has some data on waste composition, but not for the entire country.

Like many countries, Panama does not have a formal system for quantifying waste disposal, but estimates of waste generation and disposal can be made with information from studies at SWDS. One third of Panama's population (2.8 million total), lives in Panama City, where one large, sanitary landfill (Cerro Patacón) receives the majority of wastes from the city and surrounding area.[9] There are also a few large dumps, and many small, unofficial uncontrolled solid waste disposal sites throughout the country.

In Latin America, $CH_4$ emissions from SWDS are projected to increase almost 18% from 2005 to 2020.[2] In Panama, as in most of Latin America, most wastes are disposed in unmanaged sites. There is, however, a trend towards more waste management planning and towards a greater use of sanitary landfills. Although this trend has many environmental and health benefits, it also increases the generation of $CH_4$ from SWDS. Wastes deposited in landfills are subject to more anaerobic conditions than those deposited in dumps, especially in unmanaged, shallow disposal sites which occur frequently in the developing world. Increased combustion of $CH_4$ through landfill gas flaring or combustion for energy could counter this trend.

Municipal solid waste generation in Panama is expected to grow with population, and sanitary landfilling is also expected to increase. Recycling is not practiced regularly in Panama; however, materials separation does occur at many disposal sites through scavenging.[9]

## RESULTS

### Former Default Method

In Panama's emissions inventory for the year 1994, it estimated $CH_4$ emissions from SWDS to be 25.0 Gg $CH_4$.[8] SWDS is a key source (defined by IPCC as a source having a significant influence on a country's total emissions inventory in terms of percentage of overall inventory, trends, or other, qualitative criteria) of emissions of greenhouse gases from Panama, emitting 6% of the anthropogenic greenhouse gases from the country, with emissions projected to rise, and practices expected to change.[5, 8]

For this paper, emissions and emissions projections were calculated for the time series 1990-2020 using the default method from 1996 IPCC guidance and the assumptions used to develop Panama's 1994 inventory. In its 1994 inventory, Panama estimated emissions only for the landfills Cerro Patacón (Panama City) and Red Tank (Panama Canal Authority).[8] Therefore, it included only about 60 to 70 percent of all wastes sent to SWDS. As the Panamanian 1994 inventory assumed that 100% of wastes are disposed in managed SWDS, an MCF of 1 was used. The calculations also used a $DOC_f$ of 0.77, a DOC of 0.13, and a $CH_4$ content of the generated gas ($F$) of 0.5, as recommended in the Revised 1996 Good Practice Guidance.[6]

Total waste generation (374.1 Gg) from the 1994 inventory was divided by total population (2.57 million) in 1994 to determine a waste generation rate of 145 kg/capita/year. Annual historic and projected data for total population from the U.S. Census Bureau were then used to estimate waste disposal over the 1990-2020 time series.[10] This approach likely underestimates emissions because the waste quantity used to develop the per capita waste generation rate included only waste going to two landfills. The precise population of those areas is unknown and annual historic and projected data for population of these areas is not available, so total population was used as a proxy. Based on these inputs, the results the former default (1996 IPCC) assessment yielded $CH_4$ emission estimates of 23.1 Gg to 37.5 Gg over 1990-2020.

### IPCC Waste Model

Methane emissions from SWDS were then estimated with the Waste Model and 2006 IPCC regional default values: DOC = 0.19, a $DOC_f$ = 0.5, F = 0.5, and k = 0.17 $years^{-1}$ (average half-life of 4.1 years for bulk waste in a moist, tropical environment). The default 6 month time delay was used as well. The annual per capita waste generation rate of 145 kg/capita/year was selected. As this data represents only the quantity of waste disposed in managed landfills, 100% was entered for the percent of waste managed, yielding an MCF of 1. These values generated a $CH_4$ generation potential ($L_0$) value that was 5% lower than the $L_0$ value used in the former default method analysis. In the Waste Model, $CH_4$ generation in the current inventory year is affected more by past disposal practices than by current inventory year practices. Because the waste disposal quantities for the time series influencing the 1994 inventory year were less than the waste disposal quantity in 1994, and because of the slightly lower $L_0$ value, the Waste Model estimated emissions for the 1994 inventory year to be 21.0 Gg/yr, 16% lower than Panama's first national greenhouse gas inventory results for SWDS.

It is difficult to know the quantity of waste disposed in unmanaged SWDS in Panama. The 2006 IPCC Guidelines regional default value for waste disposal rates for Central America is 210 kg/capita/year. It was therefore assumed that 69% (145 kg/210 kg= 69%) of wastes sent to SWDS were managed and the remaining 31% were sent to unmanaged SWDS. The Waste Model was then used to re-calculate

Panama's 1994 inventory using a per capita waste generation rate of 210 kg/capita/year to account for the additional waste quantity disposed of in unmanaged SWDS. This simulation yielded a $CH_4$ emission estimate of 26. 7 Gg/yr for 1994, a 7% increase over the former default method analysis, which only accounted for the managed waste quantity, offsetting the effects of the lower $L_0$ estimated from Waste Model default values and the time series consideration of the FOD model. Figure I provides a comparison of the 1990-2020 time series projections of Panama's original estimates with the two 2006 IPCC Waste Model analyses.

**Projections**

In addition to assisting countries in the development of emission estimates, the IPCC Waste Model also allows countries to create emissions projections to assess the effects of changes in practice, such as increased use of sanitary landfills, waste recycling, or $CH_4$ recovery. In this section, three different waste management/emission mitigation scenarios are presented to illustrate the use of the model in evaluating alternative waste management strategies (see Figure II).

<u>Scenario 1: Increased Use of Sanitary Landfills</u>

This scenario presents the impact of the current trend in Panama towards increased use of sanitary landfills. While sanitary landfills have numerous environmental benefits, they typically lead to increased $CH_4$ emissions. This impact should be included in the emissions projections. The Waste Model easily performs this projection by adjusting the percentage of waste managed in different SWDS for the projection years. The percentage of waste going to managed landfills was increased from 69% in 2007 to 97% in 2020 (by two percentage points annually).

<u>Scenario 2: Increased Solid Waste Recycling</u>

In this scenario, the effect of a 10% decrease in land disposal quantities, through more solid waste recycling beginning in the year 2010, is evaluated. Changes in solid waste management policies that promote solid waste recycling can be incorporated in the Waste Model by adjusting the percentage of generated waste that is disposed in SWDS.

<u>Scenario 3: Increased Landfill Gas Recovery</u>

As there are few managed landfills in Panama, any landfill gas capture can have a substantial effect on national emissions trends. Based on its 1994 inventory, approximately 145 kg/capita/year of waste is disposed in managed SWDS. The Waste Model was used to estimate the $CH_4$ emissions from these managed SWDS. Methane recovery quantities were then estimated by applying a 50% gas collection and destruction efficiency at managed landfills. Figure II shows the estimated effect on national solid waste $CH_4$ emissions of landfill gas recovery beginning in 2010 at the managed landfills in Panama. As expected, $CH_4$ recovery can achieve significant reductions in the overall $CH_4$ emissions from SWDS in Panama.

## CONCLUSIONS

The 2006 IPCC Waste Model is a useful tool that makes it easier for countries to produce solid waste disposal site emissions estimates using the first order decay model, which is an improvement over the previous default method that did not take into account the rates of waste degradation and methane generation over time. It will facilitate comparison of emissions estimates between countries by providing a common framework to perform the detailed calculations in a consistent and transparent manner. The 2006 IPCC Waste Model can also be used to develop emissions projections that will allow countries to assess the impacts of different waste management and emission mitigation practices on future $CH_4$ emissions.

The 2006 IPCC Waste Model allows countries with limited data on waste disposal to produce national solid waste disposal site greenhouse gas emissions estimates over a time series, using the first order decay (FOD) model. For many countries this will improve estimates of methane emissions from solid waste disposal. Widespread use of the model could also facilitate comparison of estimates between countries, as calculations can be made with the same methodology in a transparent manner. Emissions projections produced by the model will allow countries to assess the impacts of different waste management and emission mitigation practices.

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**KEY WORDS**

Methane
Landfill gas
IPCC Waste Model
First Order Decay

**Figure I.** Estimated national SWDS $CH_4$ emissions for Panamá.

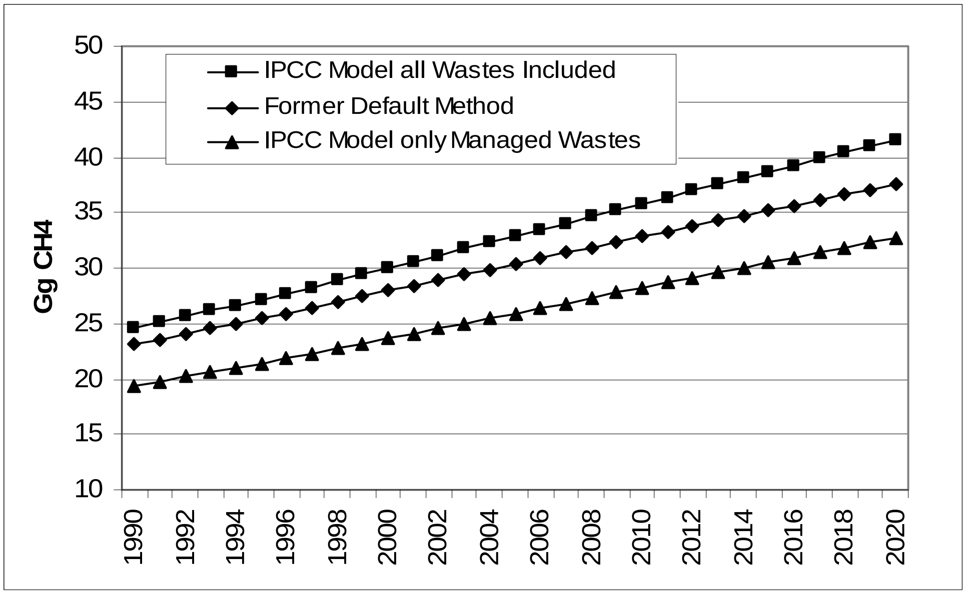


**Figure II.** Projected SWDS $CH_4$ emissions under varying waste management scenarios.