Comparison of Greenhouse Gas Emission Methodologies for Landfills

Raymond H. Huff[1], Patrick S. Sullivan[2], John J. Henkelman[2]

Extended Abstract

[1]SCS Engineers, 3900 Kilroy Airport Way, Suite 100, Long Beach, CA 90806
[2]SCS Engineers, 3117 Fite Circle, Suite 108, Sacramento, CA 95827

Principal Contact: Raymond H. Huff, Project Director, SCS Engineers, 3900 Kilroy Airport Way, Suite 100, Long Beach, CA 90806, 562-426-9544, RHuff@scsengineers.com

INTRODUCTION

Methane is a potent greenhouse gas (GHG) emitted from anaerobic decomposition, such as the decomposition that occurs in solid waste landfills. Quantifying methane emissions from landfills is more challenging than quantifying GHG from fossil fuel combustion emitted from a stack because landfills are large area sources with non-homogeneous rates of emissions occurring across the landfill surface. Also, landfill gas (LFG) generation, collection efficiency, and oxidation in landfill cover are difficult or impossible to directly measure. As a result, several methods have been developed to quantify GHG emissions from landfills, including multiple methods from the same agency which determine LFG emissions, in some cases.

Methodologies for quantifying GHG emissions from landfills have been developed for regulatory reporting, voluntary reporting, developing sustainability programs, and large scale inventories. These methods have frequently drawn from previous methodologies while simultaneously developing their own methods or factors, which have resulted in some methodologies appearing to be similar yet yielding different results. In extreme cases, these methodologies can yield results differing by an order of magnitude.

This study will compare and contrast the methodologies for estimating GHG emissions from landfills, including assumptions, default factors, the way each method was intended to be used, the strengths, and the weaknesses of each method. This study will include quantitative analysis of example sites and an analysis of under which circumstances each method should be used. The methodologies in the comparison will include the following:

- Intergovernmental Panel on Climate Change (IPCC)
- United States Environmental Protection Agency (USEPA) Mandatory Reporting Rule
- USEPA National GHG Inventory
- California Air Resources Board (CARB) GHG Inventory
- The Climate Reserve (TCR) Local Government Operations Protocol (LGOP)

- California Landfill Methane Inventory Model (CALMIM)
- Solid Waste Industry for Climate Solutions (SWICS)

GENERAL LANDFILL GHG CALCULATION METHODS

Landfill GHG emissions are typically calculated one of two ways. The first is a first order decay (FOD) model, which uses a decay rate-based model to calculate methane generation based on waste placement, rainfall, the decay rate, and the methane generation potential. The recovered methane is then deduced from the methane generation and the remainder is assumed to pass through the landfill surface. The second method is to measure the amount of methane recovered by the LFG collection and control system (GCCS) and to calculate the amount of methane generation based on an estimated fraction of methane recovered (i.e. collection efficiency). The methane recovery method cannot be used on sites without methane recovery, so FOD methods are typically used for landfills without a GCCS.

Both methods assume that all generated methane that is not recovered passes through the landfill surface. They assume that a fraction of the methane is oxidized in the landfill cover before being emitted to the atmosphere.

Critical parameters used in the FOD method include the decay rate of the waste, the methane generation potential of the waste, and the oxidation rate in the landfill cover. Critical parameters for the methane recovery method include the methane collection efficiency, the methane destruction efficiency, and the oxidation rate in the landfill surface.

The CALMIM model is the only landfill GHG emission method discussed in this paper that is not based on one of these two approaches.

REGULATORY CALCULATION METHOD

As GHG become more regulated, the regulations have included methodologies to calculate the GHG generation of landfills either as the main objective of the regulation or to determine whether a site is subject to regulation. Due to the regulatory nature of these methods, they are generally proscriptive; while they may attempt to include options for site specific information, they attempt reduce the judgment required for the calculation methodologies.

USEPA GHG Mandatory Reporting Rule

The USEPA published a mandatory GHG reporting rule on October 30, 2009 as 40 Code of Federal Regulations (CFR) Part 98. The reporting rule required the reporting of GHG at the facility level from approximately 13,000 facilities, including municipal solid waste landfills and 40 other sectors.

The USEPA reporting rule required that methane generation be calculated using two different methods. The first method is a methane generation model which draws heavily on the IPCC landfill generation model. The USEPA generation method uses historical waste placement or estimated historical waste placement and a FOD model to calculate methane generation. The second method in the USEPA Mandatory reporting rule uses landfill cover information to calculated GCCS collection efficiency. That collection efficiency is used with the measured methane collection to calculate methane generation.

Collected and destroyed methane is deducted from the modeled methane generation. The method assumes 10 percent of the remaining methane is oxidized in the landfill cover and the remaining 90 percent is emitted to the atmosphere. Emissions must be reported using both the FOD model generation method and the collection efficiency-based method. The difference in these reported values can be very different, especially for extremely dry sites or sites which are very aggressive about LFG collection.

The USEPA mandatory GHG reporting rule has been or will be integrated into the reporting rules of several states including Oregon, California, and others.

INVENTORY CALCULATION METHOGIES

Several entities, including CARB, the USEPA, and IPCC, have attempted to calculate landfill GHG emissions for large numbers of landfills in entire states, countries, or regions. For these inventories, site specific information is less important than it is for site or facility inventories. These methodologies make an attempt to determine default parameters for important parameters such as GCCS collection efficiency, methane generation potential, and oxidation in the landfill surface rather than determine site specific values for hundreds of sites.

IPCC GHG Calculation Method

The IPCC is an international scientific body tasked to review and assess information about climate change. As part of its task, the IPCC has developed GHG inventory methodologies for national and regional inventories, most recently updated in 2006. Solid waste landfills are included in the Volume 5, Chapter 3 of the IPCC methodologies, and the IPCC has released spreadsheet based tools to assist in doing landfill GHG inventories.

The IPCC uses a FOD method that calculates generated methane then deducts the methane destroyed to calculate GHG emissions. Unlike most other methodologies, the IPCC characterizes the nitrous oxide and methane emitted during methane combustion as de minimis and states that "*good practice* in the waste sector does not require their estimation."

As a method for calculating GHG inventories at a national scale, the IPCC method needs to be very flexible and accommodate regions with almost no formal solid waste industry to the United States, where a highly regulated solid waste industry exists. This wide scope is both a strength and a weakness of the IPCC method. The method is highly flexible and contains a substantial amount of default factors to use when national data is not available, but that flexibility can make the method challenging to use and regional data is sometimes not appropriate for national or especially local use.

One example of how default factors can be inappropriate of national data is the collection efficiency for the United States. The IPCC indicates that a default collection efficiency of zero (0) is appropriate in most cases, but that a collection efficiency of 20 percent is appropriate when methane is collected. The IPCC indicates that higher collection efficiencies can be justified if supporting data is available. The USEPA calculated a methane recovery fraction well over 50 percent from 2000 to 2009, and explicitly believes that that estimate is too low due to missing data. Thus, the use of IPCC default methane recovery rates for countries with well-regulated landfills is inappropriate at the national level. Similarly, the use of international default values is inappropriate for single site inventories in most cases. In aggregate, the over estimates and under estimates may yield reliable results, but care should be taken when calculating the emissions from a small number of facilities and errors are proportionally larger.

USEPA GHG Inventory Method

The USEPA releases annual GHG emission inventories. The most recent inventory was released in April, 2011 and covers the years 1990 to 2009. The USEPA method is modeled after the IPCC method but makes use of the extensive data available to the USEPA from its own databases.

The USEPA national GHG inventory for landfills uses a FOD model to calculate national methane generation. The USEPA then deducts the amount of methane destroyed based on its database of installed flare and landfill gas to energy (LFGTE) capacity and typical operating capacity. The USEPA admits that the amount of methane collected used in its inventory is probably lower than the actual amount because its inventory of LFG control devices is not complete. The remaining methane is assumed to be emitted through the landfill surface where a default 10 percent of it is oxidized. Finally, the USEPA assumes that 99 percent of methane routed to a combustion device is destroyed.

Adapting the USEPA calculations to a site level is possible but is not without potential problems. Some data, such as the installed methane destruction capacity, should be available for a single site inventory. It would be more appropriate in a site inventory to calculate emissions based on the measured methane destruction than the flare capacity and load. The largest potential source of error for a single site using the USEPA GHG inventory method is the FOD model. FOD models can produce emission estimates that are significantly different from the actual methane generation, especially for sites that are extremely arid or extremely wet. If the FOD model under calculates methane generation, deducting the methane destroyed from the methane generated will yield a result less than zero, which is nonsensical. Such errors are mitigated inventorying a large number of sites and under estimates are added to over estimates.

CARB GHG Inventory Method

Like the USEPA, CARB releases periodic GHG inventories. The most recent inventory was released May 12, 2010, but the final technical support document is not available as of July 2011. CARB has indicated that the most recent inventory was done using IPCC methodologies. The technical support document is available for 2004, which details the assumptions and adjustments to the IPCC method CARB used in their inventory.

Like the USEPA and IPCC, CARB uses a FOD model to calculate methane generation at landfills without methane recovery. CARB also uses the FOD model when methane recovery information is not available and assumes that 75 percent of the generated methane is collected. CARB has a substantial amount of waste composition data available, which it uses in the modeling to develop a state specific ultimate methane generation potentials for use in the model. For sites with methane recovery and where methane recovery data are available, CARB assumes that 75 percent of methane is captured and uses the captured methane to calculate methane generation. CARB data indicate that 94 percent of waste in landfills has some form of methane collection.

After methane generation is calculated, uncollected methane is assumed to pass through the cover where 10 percent of the methane is oxidized. CARB assumes that 99 percent of methane combusted is destroyed and that one percent of methane routed to carbon adsorption systems is destroyed. CARB include emissions of combustion byproducts methane and nitrous oxide in its GHG inventory.

Adapting the CARB method to a site specific level is possible. Because CARB uses the methane captured to calculate methane generation using default collection efficiencies when methane collection data are available, the CARB method cannot yield unreasonable results indicating that more methane is destroyed than generated. The primary weakness of the CARB method for a site specific analysis is its reliance on default factors for collection efficiency, oxidation, and methane destruction. These factors can vary significantly from site to site, so care should be taken before applying them to individual sites.

VOLUNTARY REPORTING METHODLOGIES

Several groups have developed alternative GHG calculation methodologies for landfills, including TCR, SWICS, and the California Energy Commission (CEC), which supported the development of CALMIM. The TCR and SWICS methodologies are based on either FOD modeling or calculating methane generation from methane recovery, but the CALMIM model is unique in that it does not relate methane generation, methane recovery, and methane emissions.

TCR LGOP Method

TCR is a voluntary reporting registry. Landfills are a significant source of GHG emissions from many local government operations, so TCR has included a landfill GHG emission calculation method in its LGOP.

The TCR method for sites without methane recovery is not significantly different from other FOD methane generation modeling methodologies and is derived from the IPCC model. The TCR method for calculating GHG emissions from sites with a GCCS is based on calculating methane generation based on methane collection. For sites subject to the New Source Performance Standard (NSPS) for landfills, TCR assumes that 75 percent of generated methane is collected from the entire site. For sites not subject to the NSPS, TCR assumes that 75 percent of methane is recovered from areas covered by the GCCS. Unrecovered methane is assumed to pass through the landfill surface and a default percentage of 10 percent is oxidized. TCR uses a methane destruction efficiency of 99 percent in its method, based on the USEPA destruction efficiency.

TCR's protocol indicates that site specific data can be used instead of default values when the data are available. This has included using collection efficiencies and oxidation rates calculated using the SWICS method by non-governmental entities, but TCR has indicated that such alternative methodologies will not be acceptable for governments required to use the LGOP as part of their TCR reporting. As such, the default factors in the LGOP are inflexible when site-specific data are available and indicate that default parameters are too high or too low.

SWICS Landfill Method

SWICS is comprised of public and private solid waste and recycling service providers throughout North America dedicated to advancing strategies and technologies to address the challenge of climate change and to introduce strategies to reduce and mitigate GHG emissions. As part of that goal, they have developed a method for site specific landfill GHG inventories.

The SWICS method for sites without methane collection is to use FOD based modeling to calculate methane generation, though they do not explicitly recommend a specific model. For sites with methane collection, SWICS recommends calculating a site specific collection efficiency using cover type, GCCS extent, and supporting information. SWICS classifies cover as either daily, intermediate, final, or geomembrane, then assigns a range to each type. Based on supporting information such as surface emission monitoring data, the collection efficiency can be selected from this range, characterizing the collection efficiency as low, medium, or high for the cover type. This site specific collection efficiency is then used to calculate methane generation based on methane recovery information.

Methane generated but not collected is assumed to pass through landfill cover, where a fraction of it is oxidized. Unlike most other methodologies, the SWICS method does not use a default oxidation rate of 10 percent; instead, the SWICS method calculates a site specific oxidation rate based on the cover material. Finally, SWICS uses device specific destruction rates based on source test data to calculate methane emissions from destruction devices. The SWICS method does not include a method for calculating the nitrous oxide emissions from combustion devices.

The strength of the SWICS method is that it develops site specific values for most important parameters in calculating GHG emissions from landfills. As such, it is well suited for individual site inventories. The weaknesses of the SWICS method are that it requires additional judgment from the person performing the inventory when selecting a value for the collection efficiency for a cover type from within the range of efficiencies. The extensive use of site specific information also makes the method cumbersome for analysis of large numbers of sites such as a state or national inventory.

CALMIM Method

CALMIM is a GHG emission calculation tool developed with the support of the CEC. It differs from all other calculation methodologies discussed in this paper in that it is not related to methane generation, methane capture, and methane emissions. Though it is still in a beta form, its unique approach deserves discussion. CALMIM was explicitly designed in response to the discrepancy between modeled methane generation calculated by FOD models and methane recovery observed.

CALMIM calculates the daily methane flux from landfill cover based on United States Department of Agriculture (USDA) models for climate and soil microclimate. CALMIM calculates methane emissions based on calculated methane oxidation and transport in the landfill surface.

One of CALMIM's strengths is that is the only method that does not rely on a FOD model to calculate GHG emissions from sites without methane recovery. The weaknesses of CALMIM are that it is requires extensive site specific information, especially about cover. As such, it would be difficult to use for large scale inventories. Another weakness is that it does not quantify emissions from collected methane and combustion, but this weakness is easily solved due to the wide availability of combustion emission methodologies.

EXAMPLE SITES

To illustrate the variance in GHG inventory methodologies, the emissions from two example landfills have been calculated using each of the methods described. One landfill is located in Northern California and one in Southern California. Site specific data were used when available, and methods have been adapted for single sites. Parameters for collection efficiency, methane oxidation in the landfill surface, and methane destruction efficiency of control devices are also shown where appropriate. As a simplification, methane and nitrous oxide resulting from combustion are not shown, as they are not expected to contribute significantly to GHG emissions.

Site 1 - Northern California Site

Site 1, the Northern California site, is a MSW landfill with a comprehensive GCCS. The site is subject to the landfill NSPS, conducts surface emission monitoring, and is required to demonstrate that it has sufficient methane recovery.

FOD Modeling

The landfill is located in a region receiving "normal" amounts of rainfall (20 to 40 inches per year). Its waste is not well characterized, so default waste characteristics and modeling parameters are appropriate for FOD modeling for purposes of the USEPA MRR, USEPA Inventory, and IPCC methodologies. The differences in the USEPA and IPCC models are minor and do not result in significantly different model results.

Collection Efficiency

The site has a comprehensive GCCS with methane destruction. The cover types and material are available, so the collection efficiency can be characterized for the SWICS and USEPA MRR collection efficiency. No judgment calls are required for the USEPA method, which yields a 77 percent recovery rate. The site has a good history of low surface emissions, odor complaints, and no other signs of poor methane recovery. Based on professional judgment, the high end of the collection efficiency ranges were used to estimate the methane collection efficiency for the SWICS method, which results in a collection efficiency of 94 percent. Default collection efficiencies for the CARB and TCR method are both 75 percent for Site 1.

For the IPCC method, it is clearly not appropriate to use default factors of no recovery or 20 percent recovery. The site has a comprehensive GCCS, and USEPA data estimates that at least 54 percent of the methane generation in the United States is recovered in the most recent GHG inventory. The 54 percent recovery value is probably too low for the specific site because the value is based on recovery at a national level and includes sites without methane recovery, and the database of installed methane destruction capacity is incomplete. Still, in the absence of more data, the 54 percent recovery rate is the best available data for the IPCC method.

Methane Recovery

The Site monitors methane recovery and destruction as part of NSPS compliance and now as part of the USEPA MRR compliance. As such, the site can quantify the mass of the methane recovered and routed to destruction devices.

Methane Generation

With the FOD Model, collection efficiency, and the measured methane recovery, methane generation can be calculated for all methodologies which use methane generation. These values are summarized in Table 1. Methane values are shown in megagrams (Mg), which are equivalent to metric tons.

Table 1. Site 1 Methane Generation, Collection, and Recovery

Method	Methane Recovery (Mg)	Methane Recovery Rate	FOD Methane Generation	Method Methane Generation (Mg)
USEPA MRR (Recovery)	30,000	77%		39,000
USEPA MRR (FOD Model)	30,000	Not applicable	21,000	30,000
IPCC	11,000	54%	21,000	21,000
USEPA Inventory	30,000	Not applicable	21,000	21,000
CARB Inventory	30,000	75%		40,000
TCR	30,000	75%		40,000
SWICS	30,000	94%		32,000

One anomaly that appears in the FOD model-based methane generation calculations is that the methane recovery exceeds the methane generation for the USEPA MRR FOD, IPCC, and USEPA inventory methods. The USEPA MRR was intended for use at individual sites where such a result would be unreasonable, so it assumes that the methane generation is equal to the methane recovery when recovery exceeds modeled generation. The USEPA Inventory method is intended for a national inventory where individual site anomalies disappear in the aggregate and does not make this assumption limiting methane generation at the site. It is also noteworthy that the IPCC method does not factor in the actual methane collection. By using the relatively low collection efficiency of 54 percent, the IPCC method calculates a methane recovery that is only 37 percent of the actual recovery and a methane generation that is less than the actual methane recovery.

Methane Oxidation

Of all the methods discussed in this evaluation, only the SIWCS method and the CALMIM model do not assume a default oxidation rate of ten percent. The SWICS method calculates oxidation based on the cover material, which results on an oxidation rate of 35 percent oxidation in the landfill cover, three and a half times higher than the default. CALMIM calculated oxidation based on the oxidation capacity of the cover and results in oxidation of 25 percent. Note that this oxidation rate calculated by CALMIM is not directly used in the modeling but is a result of the modeling performed.

Table 2 shows the methane oxidation rate, methane passing through the landfill cover, and the methane emitted through the cover.

Table 2. Site 1 Methane Emitted Through Cover

Method	Methane Passing Through Cover (Mg)	Methane Oxidation	Methane Emitted Through Cover (Mg)
USEPA MRR (Recovery)	9,000	10%	8,100
USEPA MRR (FOD Model)	0	10%	0
IPCC	10,000	10%	9,000
USEPA Inventory	-9,000	10%	-9,000
CARB Inventory	10,000	10%	9,000
TCR	10,000	10%	9,000
SWICS	2,000	35%	1,300
CALMIM	194	25%	164

The anomaly resulting from the USEPA inventory becomes more apparent at this step, which appears to indicate that Site 1 actually removes methane from the atmosphere. Clearly, this conclusion is unreasonable.

Methane Destruction

The site controls its collected methane through combustion in enclosed flares. The control devices at the site are all assumed to have a destruction efficiency of 99 percent by the USEPA, IPCC, TCR, and CARB methodologies. The SWICS methodology uses a destruction rate of 99.96 percent for enclosed flares. Finally, methane emissions from combustion devices were calculated using TCR emission factor methods for the CALMIM inventory. The TCR emission factor method was chosen because it is a voluntary reporting methodology that could be reasonably combined with CALMIM results. It is also noteworthy that the TCR emission factor calculations result in significantly lower emissions than the emissions calculated using the method in the LGOP. Table 3 shows the methane destruction efficiencies use and methane emissions from the combustion devices.

Table 3. Site 1 Methane Emitted From Combustion Devices

Method	Methane Destruction Efficiency	Methane From Combustion Device (Mg)
USEPA MRR (Recovery)	99%	300
USEPA MRR (FOD Model)	99%	300
IPCC	99%	110
USEPA Inventory	99%	300

CARB Inventory	99%	300
TCR	99%	300
SWICS	99.96%	12
CALMIM	Not applicable	1.4

Site 1 Totals and Conclusions

Table 4 shows the total methane emissions from Site 1 using each GHG inventory method. If the unreasonable result of the USEPA GHG Inventory method is eliminated, the calculated inventories range over an order of magnitude, from 165 using CALMIM, to 9,300 using the CARB and TCR methods. The disparity is especially apparent in the USEPA MRR method values. Both 8,400 Mg of methane and 300 Mg of methane will be reported as the GHG inventory for Site 1 under the USEPA MRR. In all cases except the USEPA MRR FOD method, the majority of emissions were from methane passing through the landfill surface, which makes estimating the collection efficiency a critical factor in insuring accuracy of the calculated emissions.

Table 4. Site 1 Methane Emissions

Method	Methane Emitted Through Cover (Mg)	Methane From Combustion Device (Mg)	Total Methane Emissions (Mg)
USEPA MRR (Recovery)	8,100	300	8,400
USEPA MRR (FOD Model)	0	300	300
IPCC	9,000	110	9,110
USEPA Inventory	-9,000	300	-8,700
CARB Inventory	9,000	300	9,300
TCR	9,000	300	9,300
SWICS	1,300	12	1,312
CALMIM	164	1.4	165

Site 2 - Southern California Site

Site 2, the Southern California site, is a MSW landfill with a comprehensive GCCS. The site is not subject to the landfill NSPS, conducts surface emission monitoring, and is required to demonstrate that it has sufficient methane recovery. The site destroys recovered methane in a flare, but the recovered methane is insufficient to run the flare at all times. As such, the GCCS and flare are operated periodically.

FOD Modeling

The landfill is located in a region considered arid for FOD modeling (less than 20 inches or rain per year). Its waste is not well characterized, so default waste characteristics and modeling parameters are appropriate for FOD modeling for purposes of the USEPA MRR, USEPA Inventory, and IPCC methodologies.

Collection Efficiency

The site has a comprehensive GCCS with methane destruction. The USEPA MRR method, yields a 75 percent recovery rate, which is the default value used in the CARB and TCR methodologies by coincidence. The site is not subject to the NSPS and does not have the monitoring data needed to justify a high collection efficiency per the SWICS method. Based on professional judgment, the low end of the collection efficiency ranges were used to estimate the methane collection efficiency for the SWICS method, which results in a collection efficiency of 54 percent. By coincidence, the SWICS collection efficiency is the same as the IPCC collection efficiency of 54 percent based on the USEPA national GHG inventory.

Methane Recovery

The Site monitors methane recovery and destruction as part of compliance with local regulations and can quantify the mass of the methane recovered and routed to destruction devices.

Methane Generation

With the FOD Model, collection efficiency, and the measured methane recovery, methane generation can be calculated for all methodologies which use methane generation. These values are summarized in Table 5. Methane values are shown in megagrams (Mg), which are equivalent to metric tons.

Table 5. Site 2 Methane Generation, Collection, and Recovery

Method	Methane Recovery (Mg)	Methane Recovery Rate	FOD Methane Generation	Method Methane Generation (Mg)
USEPA MRR (Recovery)	71	75%		95
USEPA MRR (FOD Model)	71	NA	1,800	1,800
IPCC	1,000	54%	1,800	1,800
USEPA Inventory	71	NA	1,800	1,800
CARB Inventory	71	75%		95
TCR	71	75%		95
SWICS	71	54%		131

As with Site 1, there are large discrepancies between the modeled methane generation, expected recovery, and actual recovery. Methane generation calculated using FOD modeling is more than an order of magnitude greater than generation predicted using methane recovery data. The IPCC calculation results in a methane recovery value that is an order of magnitude greater than the recovery being demonstrated in practice.

Methane Oxidation

Of all the methods discussed in this evaluation, only the SIWCS method and the CALMIM model do not assume a default oxidation rate of ten percent. The SWICS method calculates oxidation based on the cover material, which results on an oxidation rate of 30 percent oxidation in the landfill cover. CALMIM calculated an oxidation rate of 29 percent.

Table 6 shows the methane oxidation rate, methane passing through the landfill cover, and the methane emitted through the cover.

Table 6. Site 2 Methane Emitted Through Cover

Method	Methane Passing Through Cover (Mg)	Methane Oxidation	Methane Emitted Through Cover (Mg)
USEPA MRR (Recovery)	24	10%	22
USEPA MRR (FOD Model)	1,700	10%	1,560
IPCC	800	10%	720
USEPA Inventory	1,700	10%	1,700
CARB Inventory	24	10%	22
TCR	24	10%	22
SWICS	60	30%	42
CALMIM	21	29%	15

Methane Destruction

The site controls its collected methane through combustion in an enclosed flare. Table 7 shows the methane destruction efficiencies use and methane emissions from the combustion devices.

Table 7. Site 2 Methane Emitted From Combustion Devices

Method	Methane Destruction Efficiency	Methane From Combustion Device (Mg)
USEPA MRR (Recovery)	99%	0.7
USEPA MRR (FOD Model)	99%	0.7
IPCC	99%	10
USEPA Inventory	99%	0.7
CARB Inventory	99%	0.7
TCR	99%	0.7
SWICS	99.96%	0.003
CALMIM	Not applicable	0.003

Site 2 Totals and Conclusions

Table 8 shows the total methane emissions from Site 2 using each GHG inventory method. The potential for the vast difference between GHG inventories derived from FOD models and methane recovery is apparent for Site 2. While the errors from using a large number of landfills for a state or national inventory may result in a total that is reasonable, it is clear that care must be taken when evaluating a single site.

Table 8. Site 2 Methane Emissions

Method	Methane Emitted Through Cover (Mg)	Methane From Combustion Device (Mg)	Total Methane Emissions (Mg)
USEPA MRR (Recovery)	24	0.7	25
USEPA MRR (FOD Model)	1,700	0.7	1,700
IPCC	800	10	810
USEPA Inventory	1,700	0.7	1,700
CARB Inventory	24	0.7	25
TCR	24	0.7	25
SWICS	60	0.003	60
CALMIM	15	0.003	15

CONCLUSIONS

As the examples above illustrate, methodologies that are fundamentally the same but with different default factors result in significantly different calculated emissions. Default factors may be appropriate for regional or national inventories, where overestimates and underestimates can be added together to get a reasonable aggregate value, but they can lead to unreasonable values for individual sites. Therefore, care should be taken when selecting an appropriate method and factors for doing a GHG inventory for a landfill. The amount of information required for site specific methodologies such as SWICS or CALMIM may be too cumbersome for large inventories.

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