METHANE EMISSION REDUCTIONS ACHIEVED BY LANDFILL GAS PROJECTS IN DEVELOPING COUNTRIES

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ABSTRACT

The number of landfill methane emissions reduction projects implemented in developing countries has grown considerably in the past five years mainly due to the establishment of the Clean Development Mechanism (CDM) and the potential for significant revenues from methane destruction in the form of Certified Emission Reductions (CERs). Projections of CERs for these projects were developed during the planning stages in Project Design Documents (PDDs). Available monitoring reports quantifying actual CERs achieved indicate that the performance of many of these LFG projects has fallen well short of projected levels, raising concerns among project developers and financers that landfill gas projects could be an unreliable source of CERs.

This presentation will (1) summarize the latest information from monitoring reports on the performance of landfill methane emissions reduction CDM projects (covering the period of 2004 through August 2009), and (2) evaluate the extent and potential causes of the low methane recovery rates and resulting under-delivery of CERs. While conditions at landfills in developing countries present significant challenges to the successful implementation of LFG extraction projects, most of the shortfalls in expected CERs appear to be caused by unrealistic expectations provided in the PDDs, often due to the inappropriate application of landfill gas generation models designed for sanitary landfills in the U.S (i.e., LandGEM). The presentation will also describes currently available tools such as LFG generation models developed by the Intergovernmental Panel on Climate Change (IPCC) and the U.S. EPA's Landfill Methane Outreach Program (LMOP) that are more appropriate for conditions in developing countries, and that provide more realistic expectations of the potential for landfill methane emissions reductions.

INTRODUCTION

In early 2007 the World Bank commissioned SCS Engineers (SCS) to evaluate reports of significant under-delivery of actual emission reductions achieved by waste management carbon finance projects involving LFG recovery. Preliminary data from the World Bank-financed LFG projects showed significant recovery shortfalls, and these results were consistent with monitoring reports published by the United Nations Framework Convention on Climate Change (UNFCCC) showing results for many of the early CDM LFG projects. SCS' tasks for the World Bank included: (1) identifying the extent to which under-delivery of expected CERs has occurred with LFG recovery projects in developing countries; and (2) assessing the extent to which the computer models used and the related data inputs into these models contributed to the differences between the actual and estimated delivery of CERs from selected landfills. Data used in the evaluation of CER shortfalls included PDDs and monitoring reports from the UNFCCC website, and information obtained from site managers from selected international LFG projects who participated in a World Bank Workshop in April 2007 in Washington D.C. on possible causes of the shortfalls in expected LFG recovery.

The SCS report to the World Bank, "Comparison of forecast and reported methane recovery rates at selected landfills in developing countries" (SCS, 2007) was completed in November 2007. The database of 14 international LFG recovery projects with published monitoring reports that was used in the World Bank study has been expanded by SCS on an ongoing basis as more projects reported actual results. The present paper uses information in PDDs and monitoring reports for 51 LFG projects, covering the period of 2003 through August 2009.

Study Approach – Use of PDD LFG Recovery Projections

An underlying assumption in this study is that methane recovery and CER projections published in PDDs represent project expectations and are appropriate for evaluating project performance. Critics of this approach have suggested that PDDs are only a tool to use to register the project and that in many cases a business model uses different estimates of methane recovery than the PDD.

This study may over-state shortfalls in methane recovery expected by project investors to the extent that they applied more conservative models than used in the PDDs to evaluate projects. Unlike these business models, however, PDD estimates are publicly available. Because they influence public expectations and are the best available source of information, PDDs appear to be an appropriate tool for evaluating project performance.

LFG PROJECT PERFORMANCE

LFG project performance was calculated on an annual basis for 51 LFG projects that reported actual methane recovery or CERs at least once during the period covered in this analysis. In some cases multiple landfills were grouped and reported as a single project. Project performance in a given year is measured as a percentage value equal to actual methane recovery provided in monitoring reports divided by predicted methane recovery provided in PDDs. In cases where only CERs were reported, average methane recovery was calculated using a methane density of 0.0007168 metric tonnes per cubic meter (Mg/m3) and a global warming potential of 21 for methane, after adding reported baseline emission reductions. The approach of reporting performance in terms of methane recovery excludes from the evaluation CER shortfalls due to emission reduction calculation methodology.

Performance of individual projects can be measured as a simple average of the annual percentages, or a weighted average (sum of actual recovery rates in each year divided by the sum of predicted recovery rates for each year). Tables 1 through 5 summarize CDM LFG project performance for 2003 – 2005, 2006, 2007, 2008, and 2009, respectively, showing for each year the countries with CDM projects reporting monitoring results, the number of reporting projects in each country, the simple average of individual projects' performance, and the weighted average project performance.

The results of the project performance evaluation can be summarized further to show overall averages achieved in each year, as shown in Table 6.

Tables 1 – 6 show that the LFG projects are on average achieving a significantly lower methane recovery than was predicted in the PDDs. As indicated in Table 6, the simple average overall individual project performance for the analysis period is 50.5 percent and the weighted average overall project performance is 50.2 percent.

The largest number of CDM LFG projects reporting results was located in Latin American countries, particularly Brazil and Argentina, followed by Chile. China also had several projects reporting results. The performance of projects in these four countries is highlighted in Table 7, which lists the weighted average recovery rates for each year from 2003 through 2009.

TABLE 1. CDM LFG PROJECT PERFORMANCE IN 2003 - 2005

Year / Country	Number of Projects with Monitoring Reports	Average of Individual Projects' Performance (%)	Actual CH_4 Recovery / Predicted CH_4 Recovery (%)
Brazil	1	60%	60%
2003 Totals	1	**60%**	**60%**
Brazil	3	61%	56%
Costa Rica	1	41%	41%
2004 Totals	4	**61%**	**54%**
Argentina	1	21%	21%
Brazil	3	66%	53%
China	3	83%	36%
Costa Rica	1	35%	35%
Israel	1	14%	14%
Uruguay	1	99%	99%
2005 Totals	10	**62%**	**44%**

TABLE 2. CDM LFG PROJECT PERFORMANCE IN 2006

Year / Country	Number of Projects with Monitoring Reports	Average of Individual Projects' Performance (%)	Actual CH_4 Recovery / Predicted CH_4 Recovery (%)
Argentina	4	17%	22%
Brazil	4	45%	35%
Chile	2	16%	16%
China	4	38%	22%
Costa Rica	1	24%	24%
El Salvador	1	52%	52%
Israel	1	24%	24%
Mexico	2	31%	35%
Uruguay	1	80%	80%
2006 Totals	20	**30%**	**30%**

TABLE 3. CDM LFG PROJECT PERFORMANCE IN 2007

Year / Country	Number of Projects with Monitoring Reports	Average of Individual Projects' Performance (%)	Actual CH_4 Recovery / Predicted CH_4 Recovery (%)
Argentina	4	36%	29%
Brazil	10	61%	53%
Chile	6	36%	34%
China	5	36%	28%
Costa Rica	1	21%	21%
Ecuador	1	24%	24%
El Salvador	1	115%	115%
Egypt	1	11%	11%
Israel	2	44%	42%
Korea	2	77%	66%
Mexico	1	54%	54%
Peru	1	41%	41%
South Africa	1	36%	36%
2007 Totals	36	**47%**	**48%**

TABLE 4. CDM LFG PROJECT PERFORMANCE IN 2008

Year / Country	Number of Projects with Monitoring Reports	Average of Individual Projects' Performance (%)	Actual CH_4 Recovery / Predicted CH_4 Recovery (%)
Argentina	5	44%	47%
Brazil	13	79%	76%
Chile	6	55%	51%
China	5	28%	22%
Ecuador	1	13%	13%
El Salvador	1	101%	101%
Israel	1	34%	34%
Korea	1	97%	97%
Malaysia	1	38%	38%
Mexico	3	47%	42%
Peru	1	50%	50%
Thailand	1	34%	34%
2008 Totals	39	**55%**	**60%**

TABLE 5. CDM LFG PROJECT PERFORMANCE IN 2009

Year / Country	Number of Projects with Monitoring Reports	Average of Individual Projects' Performance (%)	Actual CH_4 Recovery / Predicted CH_4 Recovery (%)
Argentina	3	77%	84%
Brazil	4	91%	83%
Chile	1	76%	76%
China	3	14%	12%
Ecuador	1	11%	11%
Mexico	2	57%	62%
2009 Totals	14	**60%**	**62%**

TABLE 6. OVERALL AVERAGE CDM PROJECT PERFORMANCE FOR LFG PROJECTS

Year	Number of Projects Reporting	Average of Individual Projects' Performance (%)	Actual LFG Recovery / Predicted LFG Recovery (%)
2003	1	59.9%	59.9%
2004	4	61.3%	54.3%
2005	10	61.6%	43.9%
2006	20	30.3%	30.3%
2007	36	46.9%	48.1%
2008	39	55.4%	59.6%
2009	14	59.8%	61.8%
Totals	51	50.5%	50.2%

TABLE 7. AVERAGE PROJECT PERFORMANCE – ARGENTINA, BRAZIL, CHILE, AND CHINA

Country: Year	Argen-tina	Brazil	Chile	China
2003	--	60%	--	--
2004	--	56%	--	--
2005	21%	53%	--	36%
2006	22%	35%	16%	22%
2007	29%	53%	34%	28%
2008	47%	76%	51%	22%
2009	84%	83%	76%	12%

Further evaluation of the historic performance of CDM LFG projects can be performed by examining trends in individual project performance. Table 8 shows the number of CDM LFG recovery projects with weighted average methane recovery rates that were less than 25 percent of predicted, 25 – 49 percent of predicted, 50 – 74 percent of predicted, 75 – 100 percent of predicted, and greater than predicted.

TABLE 8. PERFORMANCE OF CDM LFG PROJECTS

Year	<25%	25%-49%	50%-74%	75%-100%	>100%
2003	0	0	1	0	0
2004	1	1	1	0	1
2005	3	2	0	3	2
2006	13	2	3	3	0
2007	9	12	9	4	2
2008	4	14	7	7	4
2009	4	1	2	6	1

Discussion of Data on LFG Project Performance

Tables 1 – 8 indicate that project performance steadily declined from 2003 through 2006, but have increased each year since 2006. The performance levels (based on the weighted averages) declined from 60 percent in 2003 to a low of 30 percent in 2006, and then increased to 48 percent in 2007, 60 percent in 2008, and 62 percent in 2009. This overall trend also can be seen in the data for the four countries with the most CDM LFG projects (Table 7) and in the number of projects in low to high performance level percentage brackets (Table 8). Table 8 is particularly helpful in highlighting the extremely poor performance levels in 2006, when 13 of 21 projects achieved less than 25 percent of predicted levels of LFG recovery.

Additional observations regarding the trends in the data are as follows:

- Declines in methane recovery at active sites which were projected to show significant increases in recovery contributed to the especially poor performance in 2006. The projected recovery increases suggest that the models assumed collection system expansions at these sites. The actual declines in recovery suggest that the system expansions did not occur, while problems with wellfield operations (such as leachate buildup) may have worsened.

- A large portion of the average LFG recovery increase in 2007 occurred at projects that had been on-line in prior years, suggesting improvements in performance occurred as a result of increased experience operating the LFG extraction systems.

Additional discussion of some of the potential causes of lower than expected methane recovery rates is provided in the following section.

POSSIBLE CAUSES OF POOR PROJECT PERFORMANCE

The low levels of actual methane recovery achieved as a percentage of projected methane recovery are not by themselves conclusive evidence of poor project performance. A reasonable argument can be made that most, if not all, LFG project shortfalls can be attributed not to "poor performance" but to overly optimistic projections of the amounts of recoverable methane. This is particularly true if the description of "overly optimistic" includes projections that fail to account for potentially predictable problems that prevent a project from achieving its estimated goals. However, it also is clear that LFG projects in developing countries face unique challenges due to difficult site conditions and problems with constructing and operating LFG systems in these countries. Thus, LFG model problems, site problems, and LFG collection system problems work in combination to create a situation where actual performance consistently fails to reach expected levels, as is detailed in the following subsections.

LFG Model Problems

LFG modeling is commonly done in the U.S. using the. EPA's Landfill Gas Emissions Model (LandGEM) (EPA, 2005) and a limited set of model input assumptions that are known as "Clean Air Act" or "inventory" values chosen by the EPA for regulating LFG emissions at U.S. landfills. The limited choice of input values required by the EPA do not allow for accurate estimates of LFG recovery from a range of U.S. landfills with different waste composition, landfill conditions, and collection system design and operations. This limitation is magnified greatly when LandGEM is applied using U.S. regulatory values to landfills in developing countries with vastly different waste characteristics and site conditions. Yet, this is exactly what has occurred, with the following predictable results:

- Because LandGEM applies a single (average) value for refuse decay rates ("k value"), it does not account for variations in waste decay rates over time. Solid waste in developing countries typically contains about 50 percent food waste which decays very rapidly, leaving behind much more slowly decaying organic materials. Once the landfill closes and disposal stops, the average decay rate will

decline rapidly, resulting in much lower LFG generation rates within a few years. Thus LandGEM tends to over-predict methane generation at closed sites, or sites where well installation is mainly limited to closed and capped areas of the landfill. This source of error is magnified in wet climates with high waste decay rates.

- LandGEM is commonly applied using values for the ultimate methane generation rate ("Lo") that are too high for the composition of wastes disposed at the site. This causes over-projection of methane generation for all years. High Lo estimates often are caused by (1) the application of a U.S. EPA regulatory default value (170 m^3/Mg), and/or (2) a failure to adjust for the high moisture content of disposed waste (since water does not contribute to methane generation). If 50 percent of waste disposed in developing countries consists of food waste with a moisture content of about 70 percent, most Lo values should be in the range of 60 to 85 m^3 per tonne of waste. Many of the projects evaluated for this study reported Lo values that were higher than this recommended range, including several with extremely high values of 160 m^3 per tonne or greater.

Another common modeling problem is the application of overly optimistic estimates of collection efficiency, resulting in significant over-estimates of methane recovery for all projection years. Estimates of collection efficiency often cite U.S. EPA estimates for sanitary landfills in the U.S. as a guide and fail to account for site conditions in developing countries and problems with the efficient construction and operation the collection system. Most developing countries may never achieve collection efficiencies approaching levels reached in U.S. landfills. Problems that are encountered at almost every site include high leachate levels and the inability to install wells in active disposal areas due to security issues. These and other issues related to site conditions, and the problems that they create for collection system operations are discussed in the following subsections.

Site Problems

Landfills in developing countries often have conditions which limit either LFG generation, LFG recovery, or both, including the following:

- Developing countries commonly have small, shallow sites with limited or no soil cover. These shallow landfills or "dump sites" will have aerobic conditions near the landfill surface, as well as greater losses of generated methane through the surface, than large, deep landfills with adequate soil cover. In many cases, these sites are not practical to develop because they require relatively large numbers of shallow wells or horizontal collectors that have a much smaller area of influence than deep wells.

- Leachate accumulation is a near universal problem in developing countries, especially at sites in rainy climates (very common in developing countries). Even sites experiencing only moderate amounts of rainfall very often have leachate problems resulting from high waste moisture content and rainfall accumulation in the waste mass due to limited soil cover and poor surface drainage. High leachate levels can severely limit methane recovery and are a major cause of poor project performance in developing countries.

- Limited waste compaction and poor or permeable soil cover also will create problems with air infiltration during methane collection.

- Fires can cause a significant reduction in the amount of organic waste available for methane generation.

- The presence of waste pickers can pose security problems and limit the availability of portions of the landfill for installing wells, particularly in the active disposal areas that tend to be the most productive in terms of methane generation.

LFG Collection System Problems

Limited experience with designing, constructing, and operating LFG collection systems in developing countries has led to poor system performance. Even where experienced project developers are involved, conditions encountered at landfills in developing countries lead to the following collection system problems that prevent the achievement of expected LFG recovery rates:

- For various reasons listed above (areas not closed with final cover installed, presence of waste pickers, high leachate accumulation) the planned schedule for installing wells is often difficult to achieve. Projections of future methane recovery need to assume a realistic schedule for phased system installation that coincides with plans for closing active disposal areas, installing final cover, and if needed protecting wellfield installation with security fencing or walls. This approach results in estimates of methane recovery that decline between periods of system installation, creating an irregular projection curve rather than one which continuously increases until site closure.

- Landfills with moderate to high precipitation will likely have high leachate levels and need to install pumps in extraction wells to collect leachate for treatment at either on-site or off-site facilities. Leachate pumps are not capable of completely de-watering a landfill, only a limited area surrounding the well. Projections of collection efficiency and methane recovery need to account for potential leachate accumulation problems.

CONCLUSIONS

Methane recovery projects in developing countries face significant challenges to project performance as a result of site conditions that can limit LFG generation, cause leachate to accumulate to levels that severely inhibit LFG extraction, and result in incomplete or delayed collection system installation in significant portions of the landfill. While these challenges are very significant, and can sometimes create insurmountable barriers to successful project implementation, the methane recovery shortfalls reported in this paper are in many instances traceable to overly-optimistic model projections using U.S. EPA's LandGEM. These unrealistic projections of methane recovery fail to adequately account for waste composition and site conditions which are very different than those at sanitary landfills in the U.S. and other developed countries. It is this author's opinion that a significant portion of the methane recovery shortfalls could have been predicted by the application of suitable methane generation and recovery models that include appropriate adjustments to account for waste characteristics and observed site conditions.

Many of the projections of methane recovery evaluated in this paper were prepared prior to the publication of LFG models developed specifically to account for conditions in developing countries. These include the IPCC model (Intergovernmental Panel on Climate Change, 2006) which was published in late 2006 and country specific models recently published by LMOP, including the Central American Model (LMOP, 2007) and the Mexico Model (LMOP, 2009). These LFG models are based on a multi-phased first order approach which separately applies different k values that reflect the large variation in waste decay rates in developing countries' waste streams. In addition, the LMOP models provide a method for developing realistic estimates of collection efficiency.

As a result of ongoing efforts by the World Bank and SCS Engineers, the under-performance of landfill methane recovery projects has become well-reported. New publicly available models published by IPCC and LMOP provide more realistic expectations of the potential for landfill methane emissions reductions. In addition, PDDs now being prepared using the latest methodologies approved by the United Nations Framework Convention for Climate Change (UNFCCC) for calculating CERs must apply the IPCC method incorporated in their model, or propose an appropriate alternative method (such as the LMOP country-specific models). These trends have resulted in improved estimates of landfill methane recovery. Finally, as more projects come on-line, resulting in greater experience at addressing the difficult challenges of implementing LFG projects in developing countries, LFG project performance will continue to improve.

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