Fachhochschule Köln
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UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ
FACULTADES DE CIENCIAS QUÍMICAS, INGENIERÍA Y MEDICINA
PROGRAMA MULTIDISCIPLINARIO DE POSGRADO EN CIENCIAS AMBIENTALES
AND
COLOGNE UNIVERSITY OF APPLIED SCIENCES
FACHHOCHSCHULE KÖLN

INSTITUTE FOR TECHNOLOGY AND RESOURCES MANAGEMENT IN THE TROPICS AND SUBTROPICS

LANDFILL GAS GENERATION AND USE ALTERNATIVES AS WELL AS FINANCING POSSIBILITIES THROUGH THE CLEAN DEVELOPMENT MECHANISM

THESIS TO OBTAIN THE DEGREE OF

MAESTRÍA EN CIENCIAS AMBIENTALES
GRADO OTORGADO POR LA UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ
Y
MASTER OF SCIENCE
"TECHNOLOGY AND RESOURCES MANAGEMENT IN THE TROPICS AND SUBTROPICS"
FOCUS AREA "ENVIRONMENTAL AND RESOURCES MANAGEMENT"
DEGREE AWARDED BY COLOGNE UNIVERSITY OF APPLIED SCIENCES

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PROYECTO REALIZADO EN EL MARCO DE:
RISK HABITAT MEGACITY PROJECT DE HELMHOLZ ASSOSIATION

PROYECTO REALIZADO EN:

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FACHHOCHSCHULE KÖLN

INSTITUTE FOR TECHNOLOGY AND RESOURCES MANAGEMENT IN THE TROPICS AND SUBTROPICS

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LA MAESTRÍA EN CIENCIAS AMBIENTALES RECIBE APOYO A TRAVÉS DEL PROGRAMA NACIONAL DE POSGRADOS (PNP - CONACYT)

Erklärung / *Declaración*

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ABSTRACT

Waste generation and management are closed linked to population, urbanization and affluence. The waste production per capita rises as a result of many factors such as migration to urban centers, population growth, change in the habits of consume, etc. The energetic potential contained in the Urban Solid Waste has gained importance in the last years; mechanisms such as the Clean Development Mechanism try to provide the right tools to encourage the inversion in projects that mean Greenhouse Gasses emissions reduction, and also to become valuable tools for the sustainable development of developing countries in cooperation with developed countries.

The energetic security also, is becoming one of the main challenges of Chile. The country imports almost three quarters of its energetic consume, which places the country in a vulnerable situation due to the volatility of the energy prices and interruptions in the supply chains. In order to promote the diversification of the energetic matrix and achieving a higher autonomy grade Chilean government has promoted the Non Conventional Renewable Energy.

The main purpose of the investigation was to set a base to understand the actual conditions of the landfills located in the Metropolitan Region of Santiago de Chile, as sources of landfill gas as a fuel. It also explored the different use possibilities for the gas, and the Clean Development Mechanism as auxiliary financing tool. The study attempted to become a useful tool which promotes the renewable energy sources and the improvement of the waste management conditions in Latin America.

To be able to have a general overview of the present situation in Chile many interviews with different Chilean organizations, mainly governmental, were done; all of them in Santiago de Chile. The literature review also provided the necessary data to perform the landfill gas projections, using the model elaborated by the US EPA, LandGEM. The model was chosen from a comparison with other existing calculation models and a Clean Development Mechanism methodological tool.

As part of the obtained and calculated information, it is remarkable that further work is needed in order to understand completely and specifically the reasons why the landfill gas is still not being completely used. More specific studies, within the economical area, are needed for the Metropolitan Region and its landfills. It is also possible to appreciate the great energetic potential of biogas, overall for the electricity generation directly in the landfills.

Chile posses a great Clean Development Mechanism market and support the investments in this kind of projects. Although the regulations are relatively new and still in the introduction phase, the Chilean future implementation of Non Conventional Renewable Energy projects seem to have a good opportunity in Chile. The particular case of the Metropolitan Region of Santiago de Chile shows many positive aspects of an adequate waste management. The three landfills operating at the present are properly designed and accomplish most of the environmental and health requirements that the Chilean governmental institutions ask.

According to the UNFCCC-CDM altogether, there are 2,245 registered project activities in the world. Among the top ten of host countries are Mexico in the 4th place after Brazil and before Malaysia, Chile is in the 9th place with a total of 37 registered project activities. An interesting point to take into account is the lack of municipal participation in the waste management in the MR, in which few Comunas take care of its own waste recollection and also the few existence of recycling programs in the MR. It is still necessary to promote these kind of programs to be able to achieve a higher biogas generation efficiency.

The application of European technology, such as the biodigestors, seems to be far from urban solid waste; but rather possible in other areas such as the agriculture or farming; organizations such as GTZ and CNE have an extended study in the potential of these areas.

RESUMEN

La generación de residuos y su gestión están estrechamente relacionadas con la población, la urbanización y la riqueza. La producción de residuos per cápita aumenta como resultado de muchos factores como la migración hacia los centros urbanos, el crecimiento demográfico, el cambio en los hábitos de consumo, etc. El potencial energético que contienen los residuos sólidos urbanos ha adquirido importancia en los últimos años, las herramientas como el Mecanismo de Desarrollo Limpio (MDL) trantan de proporcionar apoyos necesarios para fomentar la inversión en proyectos que signifiquen la reducción de las emisiones de gases de efecto invernadero, pero también de proveer herramientas valiosas para el desarrollo sostenible de los países en desarrollo a través de la cooperación con los países desarrollados.

La seguridad energética también, se está convirtiendo en uno de los principales desafíos de Chile. El país importa casi tres cuartas partes de su consumo energético, lo cual lo coloca en una situación vulnerable debido a la volatilidad de precios de la energía y las interrupciones en las cadenas de suministro. A fin de promover la diversificación de la matriz energética y el logro de una mayor autonomía, el gobierno de Chile ha promovido las Energías Renovables No Convencionales.

El principal objetivo de la investigación era establecer una base para comprender las condiciones reales de los vertederos ubicados en la Región Metropolitana de Santiago de Chile, como fuente biogás y sus posibilidades como combustible. De igual manera explorar las posibilidades de aprovechamiento del biogás, y el Mecanismo de Desarrollo Limpio como herramienta de financiación auxiliar. Uno de los objetivos del estudio es convertirse en un útil instrumento que promueva las fuentes de energía renovables y la mejora de las condiciones de gestión de residuos en América Latina.

Para poder tener una visión general de la situación actual en Chile fue necesario conducir diferentes entrevistas con las diferentes organizaciones chilenas, principalmente gubernamentales, todos ellos en Santiago de Chile. A través de la revisión bibliográfica también se obtuvieron los datos necesarios para realizar las proyecciones de emisiones gases de los vertederos metropolitanos de Santiago; gracias a la aplicación del modelo

elaborado por la EPA de los EE.UU., llamado LandGEM. El modelo fue elegido a través de una comparación con otros modelos de cálculo existentes y una herramienta metodológica del Mecanismo de Desarrollo Limpio utilizada para calcular las emisiones de metano provenientes de los rellenos sanitarios.

A partir de los datos obtenidos y calculados, hay que destacar que es necesario seguir trabajando a fin de comprender por completo y específicamente los motivos por los cuales el biogás de los rellenos sanitarios sigue sin ser completamente utilizado. Estudios más específicos, en el ámbito económico, son necesarios para la Región Metropolitana de Santiago y sus vertederos, o si es que éstos existen hace falta hacerlos de conocimiento público. El estudio permite advertir el gran potencial energético del biogás, sobre todo para la generación de electricidad directamente en los vertederos, como una de las mejores alternativas posibles.

Chile posee un gran mercado para el MDL y apoya las inversiones en este tipo de proyectos. Aunque las normativas que promueve este tipo de iniciativas son relativamente nuevas y aun están en fase de introducción, la aplicación futura de proyectos de Energías Renovables No Convencionales en Chile parece tener una buena oportunidad. El caso particular de la Región Metropolitana de Santiago de Chile muestra muchos aspectos positivos de una adecuada gestión de los residuos. Los tres rellenos sanitarios que operan en la actualidad han sido diseñados adecuadamente y llevan a cabo la mayor parte de los requerimientos ambientales y de salud que las instituciones gubernamentales de Chile requieren.

De acuerdo a la Convención sobre el Cambio Climático y el MDL (UNFCCC-CDM por sus siglas en inglés) existen 2,245 actividades de los proyectos de MDL registrados en el mundo. Entre los diez primeros puestos de los países anfitriones de estos proyectos se encuentran México en el 4 º lugar después de Brasil y antes de Malasia, Chile se encuentra en el 9 º lugar con un total de 37 proyectos registrados. Un punto interesante a tener en cuenta es la falta de participación municipal en la gestión de residuos en la RM, ya que pocas comunas se hacen cargo del manejo de sus residuos y de igual forma es importante señalar la escasa existencia de algunos programas de reciclaje en la RM. Todavía es necesario promover este tipo de programas para poder lograr una mayor eficiencia en la generación de biogás a través de la separación adecuada de los residuos sólidos urbanos.

La aplicación de tecnología utilizada en Europa y otras regiones del mundo, como los biodigestores, parece poco probable en el ámbito de los residuos sólidos urbanos; al contrario se observa mayor posibilidad en otras áreas como la agricultura o ganadería, organizaciones como la GTZ y el CNE han realizado extensos estudios del potencial de estas áreas.

ZUSSAMENFASSUNG

Abfallerzeugung und Management sind verwandt mit dem Bevölkerungswachstum, der Urbanisierung und dem Wohlstand. Die Erzeugung von Abfällen pro Kopf steigt als Ergebnis vieler Faktoren wie Migration zu den städtischen Zentren, Bevölkerungswachstum, Veränderung der Gewohnheiten der konsumieren, etc. Das energetische Potenzial enthaltet in der städtischer Abfall hat in den letzten Jahren viel Bedeutung gewonnen. Mechanismen wie der Clean Development Mechanism versuchen, die richtigen Werkzeuge zu liefern, um die Inversion in Projekte zu stärken. Die Projekte mussen Treibhausgase Emissionsminderung bedeuten, und auch wertvolle Instrumente für die nachhaltige Entwicklung der Entwicklungsländer in Zusammenarbeit mit entwickelten Ländern sein.

Die energetische Sicherheit ist einem der wichtigsten Herausforderungen von Chile geworden. Das Land importiert fast drei Viertel ihrer energetischen Konsum, dass das Land jedoch in eine prekäre Situation aufgrund der Volatilität der Energiepreise und Unterbrechungen in der Lieferkette platziert. Zur Förderung der Diversifizierung der energetische Matrix und die Erreichung einer höheren Autonomie, der chilenischen Regierung fördert Unkonventionelle Erneuerbare Energien.

Das Hauptziel der Forschung war eine Basis zu sein, um die tatsächlichen Gegebenheiten der Deponien in der Metropolregion von Santiago de Chile zu verstehen, als Quellen von Deponiegas als Brennstoff. Darüber hinaus die Recherche versucht den verschiedenen Möglichkeiten für die Nutzung des Gases und des Clean Development Mechanism als Hilfs-Finanzierung Werkzeug zu erklären. Die Studie versucht ein nützliches Tool zu werden, dass die erneuerbaren Energien und die Verbesserung der Rahmenbedingungen der Abfallwirtschaft in Lateinamerika fördert wird.

Um einen allgemeinen Überblick über die gegenwärtige Situation in Chile zu haben, viele Interviews mit verschiedenen chilenischen Organisationen durchgeführt wurden, alle von ihnen in Santiago de Chile. Die Aufarbeitung der Literatur hat die erforderlichen Daten an das Deponiegas Projektionen angebetet. Nachdem die Daten waren mit dem Modell LandGEM der US EPA ausgearbeitet. Das Modell wurde aus einem Vergleich mit anderen

bestehenden Rechenmodelle und ein Clean Development Mechanism methodisches Instrument gewählt.

Als Teil der erhaltenen Informationen und berechnete Daten, ist es bemerkenswert, dass weitere Arbeiten erforderlich ist, um vollständig und insbesondere die Gründe zu verstehen, warum das Deponiegas wird noch nicht vollständig genutzt. Genauere Untersuchungen im wirtschaftlichen Bereich sind für die Metropolregion und ihrer Deponien benötigt. Es ist auch möglich, die große energetische Potenzial von Biogas, insgesamt für die Stromerzeugung direkt in den Deponien zu merken.

Chile besitzt eine große Clean Development Mechanism Markt und unterstützt die Investitionen in diese Art von Projekten. Obwohl die Vorschriften relativ neu sind und noch in der Einführungsphase sich befinden, scheinen die künftige Umsetzung der chilenischen Projekte für Unkonventionelle erneuerbare Energien, eine gute Gelegenheit, in Chile zu haben. Der besondere Fall der Metropolregion von Santiago de Chile zeigt viele positive Aspekte einer angemessenen Abfallwirtschaft. Die drei aktuelle Deponien sind richtig angeornete und erfüllen die meisten der ökologischen und gesundheitlichen Anforderungen, die di chilenischen staatlichen Institutionen fragen.

Nach den UNFCCC-CDM Insgesamt gibt es 2.245 registrierte Projekt-Aktivitäten in der Welt. Unter den Top Ten der Gastländer sind Mexiko den 4. Platz hinter Brasilien und vor Malaysia, Chile ist in der 9. Platz mit insgesamt 37 registrierten Projektakten. Ein interessanter Aspekt zu berücksichtigen, ist die mangelnde Beteiligung an der kommunalen Abfallwirtschaft in der MR, in denen nur wenige Comunas kümmern sich um ihren eigenen Abfälle Erinnerung und auch die wenigen Existenz von Recycling-Programmen in der MR. Es ist immer noch notwendig, um diese Art von Programmen zu fördern, um der Lage sein, eine höhere Effizienz von Biogas-Generation zu haben.

Die Anwendung der europäischen Technologie, wie der Biokonverter, scheint weit entfernt von festen Siedlungsabfällen zu sein, sondern sie scheint möglich in anderen Bereichen wie der Landwirtschaft oder die Tierhaltung; Organisationen wie die GTZ und CNE haben erweiterte Studien über das Biogas-Potenzial in diesen Bereichen gemacht.

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AAU	Assigned Amount Unit
ASW	Assimilable Solid Waste
BTU	British Thermal Unit
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
CH_4	Methane
CNE	Comisión Nacional de Energía
CNG	Compressed Natural Gas
CO_2	Carbon dioxide
CONAMA	Comisión Nacional del Medio Ambiente
CORFO	Corporación de Fomento de la Producción
CPL	Consejo de Producción Limpia
CSM	Consorcio Santa Marta S.A.
DIA	Declaración de Impacto Ambiental
DNA	Designated Nation al Authority
DOC	Decomposable Organic Carbon
DOE	Designated Operational Entity
DOE	Designated Operational Entities
DSW	Domiciliary Solid Waste
EB	Executive Board
FAT	Fondo de Asistencia Técnica
FDI	Fondo de Desarrollo e Innovación
FONTEC	Fondo Nacional de Desarrollo Tecnológico y Productivo
GDP	Gross Domestic Product
GHG	Greenhouse Gasses
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit
GWP	Global Warming Potential
HFCs	Hydrofluorcarbons
IET	International Emissions Trading

INE	Instituto Nacional de Estadística
IPCC	Intergovernmental Panel on Climate Change
JI	Joint Implementation
LAC	Latin American and the Caribbean
LFG	Landfill Gas
LLC	Lomas Los Colorados
MR	Metropolitan Region
MSW	Municipal Solid Waste
NCRE	Non Conventional Renewable Energies
NMOCs	Non-Methane Organic Compounds
NOx	Mono-nitrogen oxides
OPS	Organización Panamericana de la Salud
PDD	Project Design Document
PFCs	Perfluorcarbons
PIN	Project Idea Note
PSA	Pressure Swing Adsorption
RCA	Resolución de Calificación Ambiental
SEIA	Sistema de Evaluación de Impacto Ambiental
SNG	Substitute of Natural Gas
SW	Solid Waste
SWDS	Solid Waste Disposal Sites
UNEP	United Nations Environment Programm
UNFCCC	United Nation Framework Convention on Climate Change
US EPA	U.S. Environmental Protection Agency
USW	Urban Solid Waste

1 INTRODUCTION

The potential of biogas as an energy source and the methane emissions from landfills are two issues that could be take into account to get a double benefit through the use of biogas for the different possibilities of energy production and at the same time reducing the emissions of methane to the atmosphere.

The study case is located in the Metropolitan Region of Santiago in Chile. The three landfills which serve this region are perfect examples of the "ideal" landfill for starting energy projects related to landfill gas production and use.

1.1 Motivation

The main purpose of the investigation is to be use as base for the future development of subsequent energy projects which support the use of the urban solid waste in Latin American countries as raw material for the generation of biogas. The study attempts, through the application of different models, to become a useful tool which promote the renewable energy sources and the improvement of the waste management conditions in Latin America.

The energetic potential of the landfill gas can provide electricity or other energies, such as heat or a substitute of natural gas. At the same time, the use of the landfill gas leads to the reduction of Greenhouse Gases (GHG) emissions in most of the cases, because one of its main components is methane which is twenty one times stronger than carbon dioxide for the Greenhouse Effect.

1.2 Hypothesis

The introduction of the Clean Development Mechanism (CDM) is convenient for the use of the landfill gas of the Metropolitan Region (MR) of Santiago de Chile due to the potential of big cities in Latin America for these projects and the environmental benefit that they represent.

1.3 General objective

To analyze the use of the Urban Solid Waste in Santiago de Chile for the generation of biogas, its use alternatives as well as the financial possibilities through the CDM.

1.3.1 Specific objectives

- To review the landfills on the MR of Santiago de Chile and the possible, or actual, biogas generation.
- To describe the procedures for the application of the CDM founds for projects focused in the biogas use.
- To make a general description of the financial possibilities of the CDM and how could it be adapted to the case of Santiago de Chile.
- To recommend the use alternatives of the biogas in the future of the MR of Santiago de Chile.

1.4 Problem statement

According the Organización Panamericana de la Salud (OPS) there are many issues which influence the quality and quantity of the urban solid waste (USW) in the Latin American and the Caribbean region (LAC). Some of the main topics are the increase of the population, the growing migration to urban centers as well as the industrial progress and the continuous change in the consumption level of the population; these factors along with the low adaptation of the waste management services cause an inadequate and problematic situation.

In 2001 LAC had a total population of 518 million people, out of which approximately 406 million habit urban centers. The USW generation estimated in LAC is 369.000 tons per day, as a future projection is calculated a USW production of 446.000 tons per day in the year 2015; with the assumption of a stable growth of the population and also stable consumption levels. (1)

The waste composition fluctuates through the different population centers, but it shows a constant range between 50 to 70% of food waste weight in humid base, and 25% of recyclable materials. (1)

The waste management services in the urban areas of LAC are of low quality, because it occurs mainly in open air dumps or inadequate landfills. Other more efficient alternatives are seldom use, most of them are in experimental faces. The deficient management provokes negative effects to the environment; such as the detriment of soil and urban environment, the pollution of aquifers, atmosphere, health problems in the population, etc. (1)

The insufficient waste management also affects the economy of the regions, because they do not fulfill the international environmental commerce requirements; for those economically based in tourism the USW also affect almost directly to these activities. (1) The landfills conditions also have a direct influence for the population around them because of the possible health problems and also the influence in their work activities, as in the case of the people which work directly with the waste.

In some countries of Latin America, e.g. Mexico, the recovery of recyclable materials coming of USW is done by people known as “barrenderos, recolectores, burreros and pepenadores”. In the MR of Mexico City the number of pepenadores is estimated in several thousands, among them there are children and old people, migrated farmers without lands, unemployed workers, beggars or orphans, ex-convicts, fugitives and handicapped people that mainly did not remember how they got there. In Chile the activities of the independent “recolectores” (collectors) has been developed for more than fifty years. (2) Although nowadays in the three landfills of the MR of Santiago the labor of these people has been displaced due to the new regulations in the country.

Between 60 to 80% of the USW of Latin American urban centers are collected, only a 23% of them have an adequate final disposition. Of the seven Megacities of Latin America (Mexico City, Bogotá, Caracas, Lima, Sao Paulo, Buenos Aires and Santiago de Chile) the lowest range of USW recollection are 60% for Lima and 80% for the MR of Mexico City. (3)

In Latin America the generation of Municipal Solid Waste (MSW) range between 0,37 and 2,65 kg/(inhabitant*day) with an average of 0,91 kg/(inhabitant*day). The main generators of MSW are the big cities with 1.1 kg/(inhabitant*day) per capita, while small and poor settlements generate less than 0,5 kg/(inhabitant*day). (3)

The population of the MR of Santiago de Chile, according the last census in 2002, was 6.061.185 people, which meant approximately the 40% of the total population of Chile. (4)

The waste production per capita in Santiago de Chile in 1997 was 0,87 kg/(inhabitant*day) and eight years later in 2005 it was 1,18 kg/(inhabitant*day). (3)

Most of the waste in the MR is domestic waste, which contains near 50% of organic materials; at the present time there are no relevant initiatives to promote the waste separation at home level. (4) According to the Instituto Nacional de Estadística (INE) in 2005 there was a final disposition of domestic and usable solid waste of 2.326.428 ton/year; there are three main landfill facilities for them.

It is important to mention also that landfill emissions of methane from developing countries are increasing as more controlled landfilling practices are implemented; these emissions could be reduced by both accelerating the introduction of engineered gas recovery and encouraging alternative waste management strategies. Thermal processes with advanced emission controls are proven technology but more costly than controlled landfilling with landfill gas recovery. (5)

The Comisión Nacional de Energía (CNE) and the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) mention that the growing energy consumption and the necessity of new energy sources are also important. The energetic security is becoming one of the main challenges of Chile. The country imports almost three quarters of its energetic consume, which places the country in a vulnerable situation due to the volatility of the energy prices and interruptions in the supply chains. In order to promote the diversification of the energetic matrix and achieving a higher autonomy grade Chilean government has promoted the Non Conventional Renewable Energy (NCRW). (6)

2 WASTE MANAGEMENT AND BIOGAS PRODUCTION

Waste generation is closely linked to population, urbanization and affluence. Modern waste-generation rates can be correlated to various indicator or affluence, including Gross Domestic Product (GDP)/capita, energy consumption/cap., and private final consumption/cap. A cornerstone of sustainable development is the establishment of affordable, effective and truly sustainable waste management practices in developing countries. It must be further emphasized that multiple public health, safety and environmental co-benefits increase form effective waste management practices which at the same time reduce GHG emissions and improve the quality of life, promote public health, prevent water and soil contamination, conserve natural resources and provide renewable energy benefits. (5)

According the Intergovernmental Panel on Climate Change (IPCC) the major GHG emissions from the waste sector are landfill methane (CH_4) and, secondarily, wastewater CH_4 and nitrous oxide (N_2O). (7) A landfill is a disposal site of municipal or Domiciliary Solid Waste (DSW), a determinate area of land or an excavation that receive Solid Waste (SW); this can be domiciliary, industrial, commercial and/or non hazardous sludge. (8)

2.1 Landfill

The Reglamento sobre condiciones sanitarias y de seguridad básicas en los rellenos sanitarios (Regulation of sanitary and basic safety conditions in landfills of Chile) defines proper landfills as "the final disposition facility for DSW and Assimilable Solid Waste (ASW) through their deposit in the ground, according to the disposition of the regulation, with the objective of minimizing problems and health risks of the population, as well as negative effects for the environment. Within this definition are taken into account the deposit zone and all the annexed facilities, which are necessary for the operation of the entire disposition complex". (9)

According to the Guía de Fiscalización de Sitios de Disposición Final de Residuos Sólidos Domiciliarios 2005: CONAMA – MINSAL (Guide of Control of Final disposition sites of DSW 2005: CONAMA – MINSAL) landfill is defined as "the final disposition site, which has a Resolution of Environmental Qualification and a Sanitary Authorization, those are recognized and authorized by the competent authority as the place where the home and ASW are currently and officially disposed. These sites have engineering projects which have impermeable coating, biogas and leachates management, monitoring plans of the main environmental components (flora, fauna, underground water control, monitoring of gases, smells, etc.)”. (9)

A landfill is a technique of waste final disposal which avoids health and environmental risks. This technique uses engineering principles to confine the waste in the smallest area as possible; it also anticipates problems caused by the leachates and gases produced in the landfill as a result of the decomposition of the organic material. (10)

2.2 Biogas production

When the waste is deposited in the landfill, the decomposition begins through a series of complex chemical processes. The main products of the waste decomposition are the leachates and gases, both can affect the health of the surrounding populations. (8). The leachates are defined as “the solution produced by leaching. E.g. water that has seeped through a waste disposal site and thus contains in solution various substances derived from the waste material.” (11) Methane (CH_4) production is the result of the anaerobic decomposition of the waste; due to the action of microorganisms such as bacteria, which degrade the waste, and liberate gases and other chemical substances. (8)

Biogas is defined as “a gaseous fuel of medium energy content, composed of CH_4 and carbon dioxide (CO_2); produced from the anaerobic decomposition of organic material in landfills” (12) The proportion of the gases, which compose the biogas, depends on the organic fraction of the waste composition. (13)

Biogas is produced during anaerobic digestion of organic substrates, such as manure, sewage sludge, the organic fractions of household and industry waste, and energy crops. It is produced in large scale digesters found preliminary in industrial countries, as well as in small scale digesters found worldwide. Biogas is also produced during anaerobic degradation in landfills and is then referred to as landfill gas (LFG). (14)

LFG is produced during anaerobic digestion of organic materials in landfills and is very similar to biogas. Its CH_4 content is generally lower than that of biogas, and LFG usually also contains nitrogen from air that seeps into the LFG during recovery. LFG can also, in contrast to e.g. biogas from farms, contain a great number of trace gases. (14) It is important to stress that both the CH_4 and N_2O from the waste sector are produced by microbial and consumed with rates controlled by temperature, moisture, pH, available substrates, microbial competition and many other factors. (See Table 1) As a result CH_4 and N_2O generation, microbial consumption, and net emissions rates routinely exhibit temporal and spatial variability over many orders of magnitude, exacerbating the problem of developing credible national estimates. (7)

The most important physical changes of the waste in the landfill are related to the compression, the circulation of gases within and outside the landfill, the entry of liquids in the interior of the landfill and to the soil, as well as the settlements caused by the decomposition of the organic material in the landfill. (13)

Landfill CH_4 recovery and optimized wastewater treatment can directly reduce GHG emissions. GHG generation can be largely avoided through controlled aerobic composting and thermal processes such as incineration for waste-to-energy. Moreover, waste prevention, minimization, material recovery, recycling and re-use represent a growing potential for indirect reduction of GHG emissions through decreased waste generation, lower raw material consumption, reduced energy demand and fossil fuel avoidance. (5)

Table 1. Factors that affect the biogas generation process in a landfill

Parameter	Influence
Kind of substrate (available nutrients)	The main nutrients of the anaerobic bacteria are carbon elements and nitrogen, present in the USW within the organic material in decomposition.
Acidity (pH)	Optimal pH for the fermentation in anaerobic phase: 7-7,5; CH_4 production can be: 6,5-8. If pH decreases, metanogenic bacteria could stop growing and CH_4 production would decrease.
Humidity content	One of the most decisive parameters in a landfill. If it rises, decomposition process accelerates notoriously. It is convenient to re-circulate the leachates to add humidity to the waste.
Mixture and size of the particles	Size of SW elements increases the superficial area of the waste, allowing faster decomposition and percolation of liquids in the waste mass. If the SW is mixed the anaerobic organisms get in contact with their nutrition source.
Cover	The periodic and systematic covering of the SW avoid its contact with the air allowing anaerobic conditions. As soon as these happens as soon as the anaerobic decomposition starts.
Compressing	Compacting during the disposal process, causes direct contact between the nutrients and humidity, and also reduces the starting time of the anaerobic degradation.
Weather and Geology	Weather can modify the landfill's humidity content; also geology can play along with weather in case of intense raining, if topography has an important slope it could be possible to present erosion.

Modified from (Velazquez Clavijo, 2005)

The different component of the waste decomposes at different rates, for example, food waste will decompose faster than paper products. Even though leather, rubber and some plastics are organic materials, they usually resist decomposition. (8)

LFG is considered a local fuel source and a renewable energy resource, the capture and use of the gas are relatively simple. The gas supply from a landfill is constant, 24 hours – 7 days a week, in the calculated times of the landfill's emissions. There are proved technologies for the use of LFG, and its use means reductions of the emissions which affect the environment. In the process of biogas use the CH_4 and other organic elements of the gas are destroyed. The landfill has also another source of incomes and it promotes the local economy development, the final user obtains benefits as well reducing the fuel costs and using renewable energy sources. (15)

2.2.1 Classification

To understand the common classification of the landfill gas is important to know that a BTU is defined as British Thermal Unit which is a unit of heat equal to the amount of heat required to raise one pound of water one degree Fahrenheit at one atmosphere pressure; it is equivalent to 251.997 calories. (16) According to the calorific values and possible uses of the gas, it is possible to classify it in two categories: (15)

2.2.1.1 Medium BTU fuel

This gas is mainly used directly and with little treatment for its commercial, institutional and industrial use; in order to supply water heaters, ovens, dryers, waste incinerators and conventional electricity generators. Some of the new approaches for the use of this kind of biogas are its use as fuel in greenhouses as a source of energy and heat, but also using the carbon dioxide which can help to improve the grow of the plants within the greenhouse, ceramic ovens and as fuel for the evaporation of the leachates of the landfill, this helps to reduce the treatment costs. Usually contains a 50% of CH_4. (15)

2.2.1.2 High BTU fuel

The biogas is purified until levels of 92% to 99% of CH_4, removing the carbon dioxide within it. The most common end use of this fuel is like a substitute of Natural Gas (NG) or Compressed Natural Gas (CNG). The disadvantages of the use of biogas as a substitute of

NG are mostly economical, because of the costs of the necessary treatments to achieve the existing regulations for the injection of gas to the pipelines. (15)

2.3 Landfill gas management

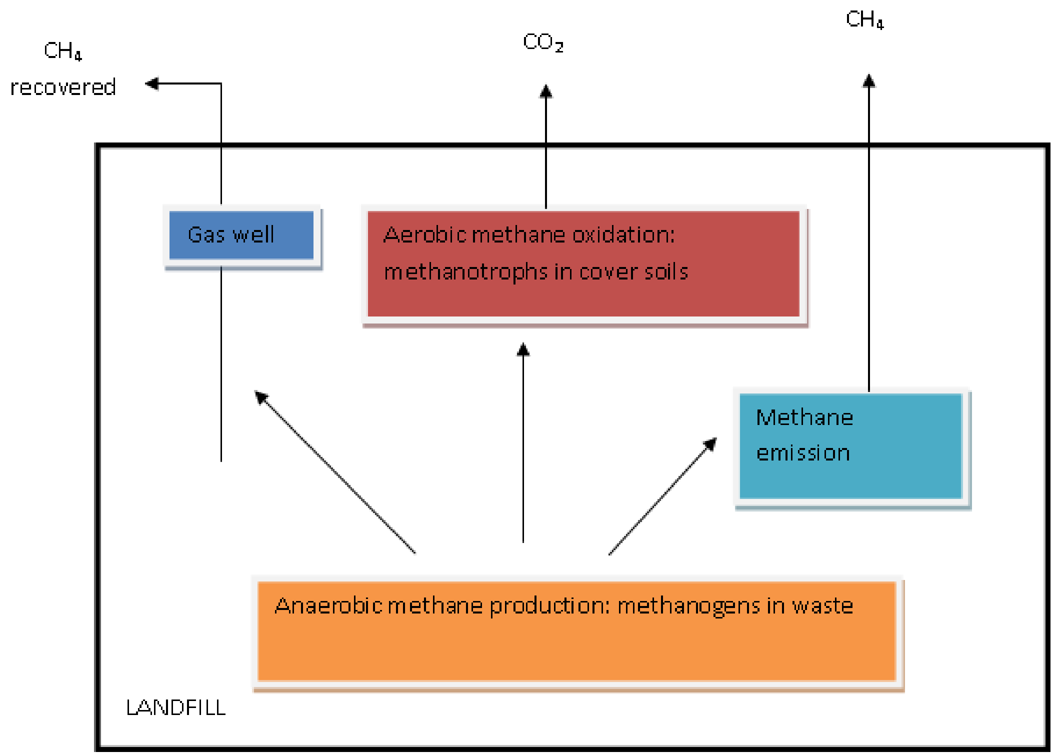
The U.S. Environmental Protection Agency (US EPA) has determined that emissions from MSW landfills cause, or contribute to air pollution that may reasonably be anticipated to endanger public health or welfare. Some Non-Methane Organic Compounds (NMOCs) are known or suspected carcinogens, or cause other non-cancer health effects. The NMOCs are defined as all organic pollutants, excluding CH_4; they account for aldehydes, ketones, alcohols, benzene, toluene and other pollutants that are not hydrocarbons but are precursors of ozone. Public interest concerns include the odor annoyance from the LFG and the potential for CH_4 migration, both on-site and off-site, which may lead to explosions or fire. The CH_4 emitted from landfills is also a concern because it is a greenhouse gas and contributes to global climate change. (17)

The CH_4 form the landfills needs to be ventilated and extracted because of its properties, it is a colorless, odorless and flammable gas. In combination with the air, it forms explosive mixtures with it and contributes to the "greenhouse effect" (18). The UNFCCC and the Kyoto Protocol define the Global Warming Potential (GWP) of CH_4 in 21 times higher than CO_2 within a time horizon of 100 years and referenced to the updated decay response for the Bern carbon cycle model and future CO_2 atmospheric concentrations held constant at current levels. (19) The gases recovery systems in the landfills are not completely efficient, on the contrary it is estimated that they rarely exceed the 70-75% of efficiency. The higher efficiency levels are not constant during the life of the landfill. (8)

It is possible to evacuate the biogas from landfills with a drainpipe system which can be active or passive. The active drainage consists in the suction of the biogas through a blower. For the passive drainage it is only a control of the natural diffusion of the gases, in order to evacuate them through the designed wells. (8)

If there are a passive recovery system for the gas is important to burn it, because it goes out of the chimney almost undiluted. The flux of LFG is represented in Figure 1.

Figure 1. Landfill gas flux



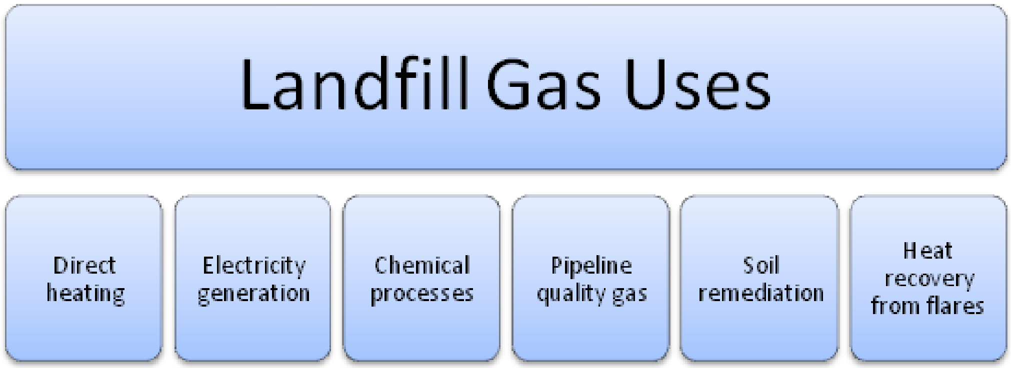
Source (IPCC, 2007)

2.4 Use possibilities

LFG can be sold as high-BTU pipeline-quality gas to various utility companies, medium-BTU gas to nearby businesses for use in boilers, space heating, or other applications; it can be also used as fuel for the on-site generation of electricity. Other newer technologies for LFG include use as an alternate vehicle fuel, for methanol, production and in fuel cells (See Figure 2). (20)

Production and utilization of biogas has several environmental advantages because it is a renewable energy source, it reduces the release of CH_4 to the atmosphere compared to traditional manure management or landfills, it can be used as a substitute for fossil fuels and also if the biogas is produced in a bio-digester the high quality digestate can be used as fertilizer. (14)

Figure 2. Landfill gas use possibilities



Source: Themelis, Ulloa; 2006

The energetic amount of the biogas is related to the CH_4 quantity in the gas. This amount varies according to the composition of the decomposing material. A cubic meter of CH_4 has an energy content of around 10 Kilowatt-hour (9.97 kWh). For example, if the fraction of CH_4 in the biogas is 55%, the energy use of 1 m^3 of biogas would be 5.5 kWh. As an average, the calorific power of 1 m^3 of biogas is 21.6 MJ, and the same amount of gas is equivalent to approximately 0.6 l of fuel oil. (21)

To increase the quality of the raw biogas, the gas is usually cleaned of unwanted substances such as hydrogen sulfide, oxygen, nitrogen, water and particulates. The main reason for doing this is to prevent corrosion and mechanical wear of the equipment in which the biogas is used. (14)

2.4.1 Direct heating applications

The biogas can be use for thermal applications such as industrial boilers; also as fuel for space heating and cooling, for example in Greenhouses. (22) Medium-BTU LFG is much easier to process and can be used as a fuel in boilers and furnaces. (20)

With direct combustion and boiler applications, the most common approach is to apply minimum gas cleanup, limited to condensate knockout and optional filtration. To date, this has appeared to work well for most boiler applications. Boiler tubes, that might be considered potential candidates for fouling or corrosion, appear to experience no undue amount of either. For the boilers use some design adjustment most be made because of the lower energy content of the landfill gas, e.g. to double the gas pressure, with a larger compressor; or by doubling the burner orifice area. It is generally more economical to limit pressure requirements at the boiler and keep the whole system at a lower pressure. (23)

2.4.2 Electricity generation

Some of the most promising technologies involve the utilization of LFG as an energy source in power generation. In addition to helping conserve valuable alternative energy resources, direct LFG utilization results in reduced NMOCs and CH_4 emissions. The choice of the type of power-generation facility using LFG depends mainly on the quantity and rate of LFG produced. Steam and gas turbines are appropriate only for very large landfills; gas engines have a smaller capacity. The most common energy application for LFG is an engine or turbine fuel in the on-site generation of electricity. (20)

The gas engine had an advantage over the gas turbine in generating electricity aspect and produced less waste heat. The steam turbine had better perform the energy recovery system at the same time because it used all the energy producing the steam and less in generating electricity. The direct gas usage facility mostly produced the steam for operating system. The choice of electricity generation facilities depends on the landfill scale, namely LFG generation amount. The gas engine is frequently used in small-scales, and steam turbine over large-scale landfills. (20)

In the technical criterion, the most effective facility is the gas engine, the next steam turbine, and the last gas turbine. But there are little differences in electricity efficiency of LFG utilization. In the technical stability aspect, the gas engine is the most stable because of wide distribution and many examples of field application. Gas turbine is also stable owing to the many cases of field application. In the technological durability aspect, the steam turbine is very good because there are so many corrosive and volatile gases in LFG, but they are not directly contacted with steam turbine. The gas engine is corroded by continuous contact with LFG, and it is the worst in technical durability. (20)

The incident facilities of LFG electricity generation must have the pretreatment system like the dehydration and desulfuration process. It is necessary for gas engine and gas turbine to equip the high pressure compressor. The steam turbine is needed to supply the stream condensation facility and boiler. (20)

2.4.3 Substitute of Natural Gas (SNG)

Through the purification of the landfill gas it can be used as vehicular fuel, also incorporated to the natural gas network as substitute of natural gas. (22) Producing 950 BTU, pipeline-quality gas from LFG requires extensive processing to remove the moisture, carbon dioxide, heavy hydrocarbons, and trace components. The reason that electrical facilities exceed gas processing facilities is because the equipment associated with producing electricity is simpler and cheaper than that for the production of pipeline-quality gas. (20)

The main difference in the composition between biogas and natural gas relates to the carbon dioxide content. Carbon dioxide is one of the main components of biogas, while natural gas contains very low amounts. In addition, natural gas also contains higher levels of hydrocarbons other than CH_4. These differences result in a lower energy content of biogas per unit volume compared to natural gas. (14)

Upgrading biogas means to increase the CH_4 levels to achieve the levels of natural gas. Higher CH_4 content is achieved by extracting the CO_2 from the biogas. Organic materials, such as chlorine, sulphur, etc. also need to be removed in a pre-treatment or post-treatment process. Cleaning is important in order to prevent air pollution, contamination of surface water, as well as pollution of engines, for example. (24)

Determining which the best is, most efficient upgrading technique for a particular situation depends on so many factors that this can only be decided on an individual basis. However, a few initial guidelines can be given. If the plant capacity is over 2000 Nm^3 per hour, then membrane filtration is less economically viable. If residual heat is available at the location, this is an extra plus point for amine gas cleaning, because this results in extremely low electricity consumption. Only the cryogenic technique produces industrial-quality liquid CO_2. In order to make a correct comparison of investment and operation costs, the necessary costs for pre/post treatment also need to be taken into consideration, as well as the savings in useful utilization of residues. Among the upgrading techniques are the Liquid absorbs CO_2, separating liquid CO_2, Active carbon adsorbs CO_2, Separating CO_2 via membrane, and Pressure Swing Adsorption (PSA) (24)

With the PSA technique, carbon dioxide is separated from the biogas by adsorption on a surface under elevated pressure. The adsorbing material, usually activated carbon or zeolites, is regenerated by a sequential decrease in pressure before the column is reloaded again, hence the name of the technique. An upgrading plant, using this technique, has four, six or nine vessels working in parallel. During regeneration the pressure is decreased in several steps. The gas that is desorbed during the first and eventually the second pressure drop may be returned to the inlet of the raw gas, since it will contain some CH_4 that was adsorbed together with carbon dioxide. The gas desorbed in the following pressure reduction step is either led to the next column or if it is almost entirely CH_4 free it is released to the atmosphere. (14)

The most common technologies for biogas upgrading are the water scrubber technology and the PSA-technology. Gas upgrading is normally performed in two steps where the main step is the process that removes the CO_2 from the gas. Minor contaminants are normally removed before the CO_2-removal. (25)

3 Clean Development Mechanism

The weather changes naturally, but scientists agree that the growing concentrations of anthropogenic emissions of GHG to the earth atmosphere are driving to a climate change, which is considered as one of the most serious threats to the global environment; according to the predictions these changes will have a negative impact on the humans health, their food security, economical activity, water and other natural resources. (6)

The Kyoto Protocol was adopted in December 1997 during the third conference of members of the United Nations Framework Convention on Climate Change (UNFCCC) and has created legally binding obligations for 38 industrialized countries, at the beginning, to diminish their emissions of GHG to an average of approximately 5,2% below their levels in 1990 over the period of 2008 to 2012. (26) According to the UNFCCC nowadays there are 41 countries registered as Annex I parties.

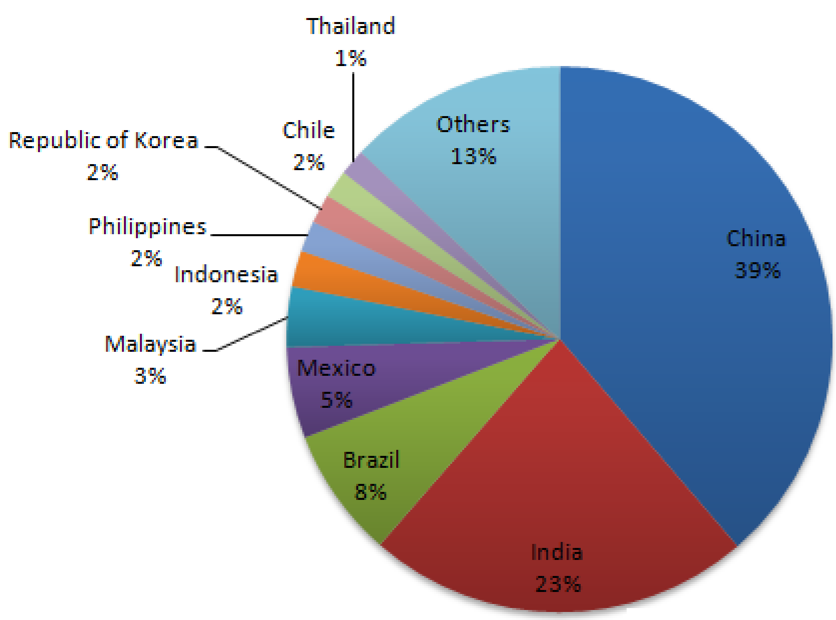
The purpose of the protocol is to support the member countries to achieve their reduction goals of the GHG emissions; the protocol defines three innovator “flexibility mechanisms” to diminish the costs of accomplish these goals. The mechanisms are integrated by the CDM, Joint Implementation (JI) and International Emissions Trading (IET). These mechanisms give countries and private sector companies the opportunity to reduce emissions anywhere in the world and they can then count these reductions towards their own targets. (26).

While the CDM lowers the cost of compliance with the Protocol for developed countries, developing countries will benefit as well, not just from the increased investment flows, but also from the requirement that these investments advance sustainable development goals. The CDM encourage developing countries to participate by promising that development priorities and initiatives will be addressed as part of the package. This recognizes that only through long-term development will all countries be able to play a role in protecting the climate. (27)

3.1 CDM in Chile

According to the UNFCCC-CDM altogether, there are 2,245 registered project activities in the world. Among the top ten of host countries are Mexico in the 4th place after Brazil and before Malaysia, Chile is in the 9th place with a total of 37 registered project activities (See Figure 3). Nowadays, of a total of 420,574,223 CERs issued by the EB worldwide, there are in Chile 4,938,788 CERs issued.

Figure 3. Registered Project Activities by host country



Source: http://cdm.unfccc.int, 2010

3.2 Greenhouse Gases

The GHG defined within the protocol are: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), Hydrofluorcarbons (HFCs), Perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6) (28). The protocol allows the member countries to decide which of the six gases will form part of their national emission reduction strategy; there are some activities within the land-use change and forestry sector which are also covered by the protocol, such as deforestation and reforestation. (29)

Most of the radiant energy form the sun is concentrated in the visible and near visible parts of the light spectrum. Various components of earth's atmosphere absorb ultraviolet and infrared solar radiation before it penetrates to the surface of earth, but the atmosphere is quite transparent to visible light. Absorbed by land, oceans, and vegetations at the surface, the visible light is transformed into heat and re-radiates in the form of invisible infrared radiation. The atmosphere contains molecules that absorb the heat and re-radiate the heat in all directions, reducing the heat radiated out to space. Called "greenhouse gases" because they serve to hold heat in like the glass walls of a greenhouse, these molecules are responsible for the fact that the earth possesses temperature suitable for our active and complex biosphere. (30)

Human activities are making the covering of the earth "thicker"- the natural levels of these gases are being supplemented by emissions of carbon dioxide from the burning of coal, oil and natural gas; by additional methane and nitrous oxide produced by farming activities and changes in land use; and by several long-lived industrial gases that do not occur naturally. The result, known as the enhanced greenhouse effect", is a warming of the earth's surface and lower atmosphere. (31)

The CDM is a plan for the reduction of the GHG emissions in cooperation between countries; the mechanism is based on the provision of the Article 12 of the Kyoto Protocol. The parties of the cooperation are the countries which signed the protocol (Annex I Parties) and the so called "developing countries" which have no commitment of emission reduction under the Kyoto protocol. The main purpose of the CDM is to support the performance of the goals of reduction of GHG for the developed countries, and also to contribute to the sustainable development of the developing countries. Within the CDM, the investor countries implement projects (for example: projects of biogas recovery with energy generation) which result in the reduction of the GHG emissions in the territories of the country which does not have a commitment of reduction. As a result the investors can acquire all or part of the Certified Emission Reductions (CERs) which result of the projects. The host countries will obtain also benefit of the CDM project (26)

The CDM will include projects within the sectors of end-use energy efficiency improvements, supply-side energy efficiency improvement, renewable energy, fuel switching, agriculture, industrial processes and sinks projects. The CERs are then generated in developing countries which do not have an Assigned Amount Unit (AAUs), therefore the total amount of emission saved are for the investor and its AAUs rises. The total amount of GHG emissions would grow if the CERs were higher than the actual reduction, because of that the CDM demands that the project follows strict procedures which are established by the Executive Board (EB) with the intention of ensure that CERs amount won't be overestimated. The procedures includes a third part, called Designated Operational Entities (DOE), which advises the subject of the emission reduction through procedures called of validation and verification, and a final approval of the project register and the provision of CERs by the EB (26). It is important to mention that the Annex I Parties must abstain from using CERs generated through nuclear energy to meet their reduction target. (29)

In order to make small project competitive the Marrakech Accords establish a fast track for small-scale projects with simpler eligibility rules – renewable energies up to 15 MW, energy efficiency with a reduction of consumption either on the supply or the demand side of up to 15 GWh/yr, and other projects that both reduce emissions and emit less than 15 kilotons of CO_2 equivalent annually. (29)

The UNFCCC differentiate the CDM in three main groups (6):

a) Large Scale Projects
b) Small Scale Projects
c) Afforestation and Reforestation Projects

3.2.1 Executive Board

The EB is the formal governance body established under Article 12 of the Kyoto Protocol to oversee the implementation and administration of the CDM, under the authority and guidance of the Conference of Parties. (32)

The CDM is supervised by the EB, which itself operates under the authority of the Parties. The EB is composed of 10 members, including one representative from each of the five official UN regions (Africa, Asia, Latin America and the Caribbean, Central Eastern Europe, and OECD), one from the small island developing states, and two each from Annex I and non-Annex I Parties. (33)

The EB will accredit independent organization –known as operational entities – that will validate proposed CDM projects, verify the resulting emission reductions, and certify those emission reductions as CERs. Another key task of the EB is the maintenance of a CDM registry, which will issue new CERs, manage an account for CERs levied for adaptation and administration expenses, and maintain a CER account for each non-Annex I party hosting a CDM project. (33)

3.3 Project Eligibility

All project of emissions reduction of GHG, which takes part of the CDM has to fulfill the conditions of: (6)

- Reduce some of the GHG indicated in the Kyoto Protocol.
- Voluntary participation.
- To reduce emissions considered additional to those produced in absence of the project.
- To demonstrate real benefits, measurable and in a long term related to the GHG mitigation.
- To contribute to the sustainable development of the country.
- To be developed in a country that has ratified the Kyoto Protocol and has a Designed National Authority (DNA) for the CDM

Small-scale is a category of CDM projects which benefits from simplified modalities and procedures not to slow down their development. A project is categorized as small-scale if it complies with at least one of the following characteristics: (34)

- Type I: Renewable energy project activities with a maximum output capacity equivalent of up to $15MW_{electrical}$.
- Type II: Energy efficiency improvement project activities which reduce energy consumption, or the supply and/or demand side, by up to the equivalent of 15 $GWh_{electrical}$/year.

- Type III: Other project activities, non-included in the categories mentioned before, that both reduce emissions by sources and directly emit less than 15 000 tCO_2e/year. In a project activity with more than one component that will benefit from simplified CDM modalities and procedures, each component shall meet the threshold criterion of each applicable type.

To prove the additionality is crucial for the viability of a project as part of the CDM, because it is one of the most fundamental conditions for the projects to get the benefits of the mechanism. As guidance the Executive Board (EB) approved a Tool for the demonstration and assessment of additionality. (6)

The CDM project must lead to real, measurable, and long-term benefits related to the mitigation of climate change. The additional greenhouse gas reductions are calculated with reference to a defined baseline. The Kyoto protocol specifies that the purpose of the CDM is to assist non-Annex I Parties in achieving sustainable development. There is no common guideline for the sustainable development criterion and it is up to the developing host countries to determine their own criteria and assessment process. (27)

3.4 CDM project cycle

The project developer has to go through many stages of the project cycle of the CDM, with the purpose of registering the project with the EB. (See Figure 4)

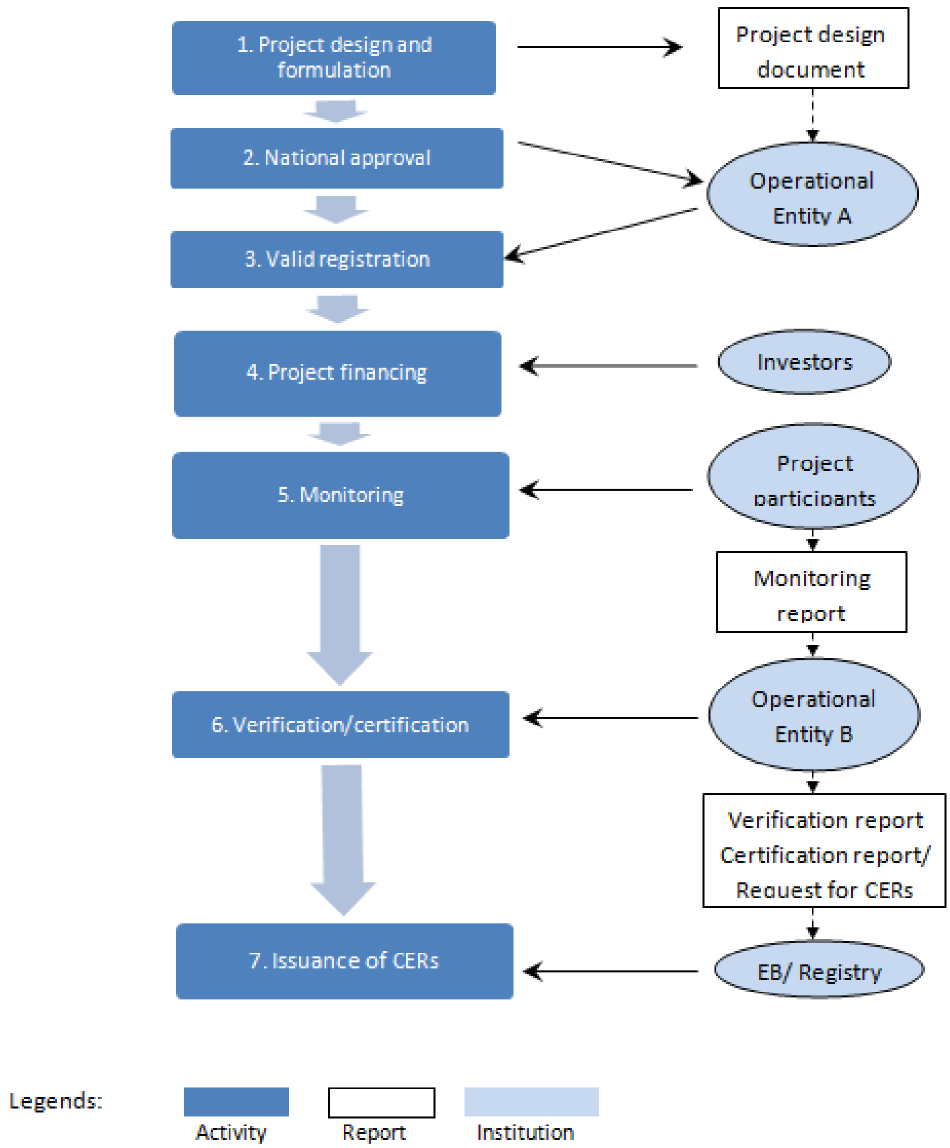
3.4.1 Project design and formulation

During this stage the project developers have to elaborate the Project Design Document (PDD), which is the standard document for the beginning of CDM projects. The PDD is presented to the Designated Operational Entity (DOE), it includes the quantity of the emissions reductions of the project. (6)

The PDD has a general description of the project, the application of Base Line methodologies, the Crediting Period which is the duration period of the project, methodology application and monitoring plan, estimation of GHG emissions, environmental impacts and stakeholder’s comments. (6)

The most recent version of the PDD is available in the website of the UNFCCC-CDM through its website. Every project developer must check the latest version of the PDD before starting. (35)

Figure 4. CDM Project Cycle



Source: (UNEP RISOE CENTRE ON ENERGY, 2004)

Before the elaboration of the PDD it is possible to elaborate a document with less detailed information with the purpose of knowing the potential of the project, this document is the Project Idea Note (PIN). (6)The PIN is a note prepared by a project proponent regarding a project proposed for a potential CER buyer, such as the World Bank or SENTER. The PIN is often set out in a given format as with the World Bank which has a PIN that is generic across all World Bank managed funds. (33)

The PDD presents information on the essential technical and organization aspects of the project activity and is a key input into the validation, registration, and verification of the project as required under the Kyoto Protocol to the UNFCCC. The PDD also contains information on the project activity, the approved baseline methodology applied to the project. It discusses and justifies the choice of baseline methodology and the applied monitoring concept, including monitoring data and calculation methods. (26)

3.4.2 National approval

The approval process is done by the Designated National Authority (DNA), whom must ratify that all the parties are participating voluntarily and the CDM project facilitates the sustainable development of the country. (6) The host country should develop national criteria and requirements to ensure a coherent, justifiable and transparent assessment. (27)

In order to obtain the National Approval in Chile it is necessary to have a RCA (Resolución de Calificación Ambiental), or if it does not apply, the necessary sectorial licenses; also a description of the CDM project, a sworn declaration of the project developer in which he confirms that is presenting the project voluntarily, and the powers of the legal representative of the project. (6)

3.4.2.1 Designated National Authority (DNA)

A host country must establish a Designated National Authority, which will have the responsibility to decide whether the project activity makes a contribution to achieving the country’s sustainable development goal and whether the country agrees to participate in the project. One of the key elements for attracting CDM investments is the host country’s application of quick and transparent procedure for screening, evaluation and approving projects. To achieve this goal, the National CDM Authority should implement a standardized system for this activity. (33)

In Chile, the DNA function is assumed by the directive board of CONAMA. This instance delegates the operational aspects to an executive board chaired by the executive director of CONAMA and composed of representatives of the CONAMA, the exterior relation ministry, the agricultural ministry, the National Commission of Energy, the clean production secretary and the ministry or service competent in the project activity. (34)

The DNA must obtain an overview of the existing legal environment and establish an enabling regulatory framework for evaluation and approval of CDM projects; including development of national criteria and respective information requirements to ensure a coherent, justifiable and transparent assessment of CDM projects in accordance with the CDM Executive Board's decisions. Also the DNA must ensure the compliance of CDM projects with relevant national policy and regulatory regimes, and finally to elaborate guidelines and procedures for project approval. (27)

3.4.3 Validation and registration

The validation is the independent evaluation process of a project and must be done by a Designated Operational Entity (DOE), to prove if it fits to the CDM requirements and to analyze the application of the base line methodology of the project. To achieve this, the DOE bases the evaluation on the PDD, the baseline methodology, the report with the synthesis of the stakeholder's comments and the approval of the host country. (6)

The DOEs will typically be private companies such as auditing and accounting firms, consulting companies and law firms capable of conducting credible and independent assessments of emission reduction. The DOEs can be accredited for 15 sectoral scopes, the project participants should therefore check under which of the scopes their project fits, and choose for validation a DOE that is accredited for that scope. The list of DOEs is available in the UNFCCC-CDM website. If the project is validated, the operational entity will forward it to the EB for formal registration. (27)

3.4.4 Project Financing

With the validation and registration of the project the actions to implement the project can take place, these activities generate an emission reduction credit as well as other conventional benefits to create financial income. Project financing is a common and crucial part of project implementation in every project. There are multilateral and bilateral sources and founding to develop CDM projects, this project financing also involves risks from different sources and requires project developers to properly mange any potential risks, including project risks, political risks, and market risks. Project risks include whether the project meets all the requirements of the CDM and whether the project will generate the emission reduction credits estimated in the PDD. Political risks include the entry into force of the Kyoto Protocol and ratification of the Protocol by participating governments. Market risks include the price of CERs and transaction costs. (27)

The cost of transaction for the both scales of the projects in Chile (See Table 2) is usually estimated per stage with a total of approximately US $41,800. (6)

Table 2. Administrative costs of a small scale project

Project stage	Small scale project Cost (US $)
Initial preparation of the project	4,800
Development of the PDD	10,800
Validation	6,000
Registration	5,000
Evaluation	8,000
Initial verification	3,000
Verification	1,200
Certification	3,000
Total	41,800

Source (CNE,GTZ; 2007)

In case of the large scale project (See Table 3) the costs are summarized also in stages, but the costs may vary a little bit most in comparison with the small scale projects. (6)

Table 3. Administrative costs of a large scale project

<table>
<tr><th>Project stage</th><th>Large scale project - Cost (US $)</th></tr>
<tr><td>Project design</td><td>20,000 – 30,000</td></tr>
<tr><td>National Approval</td><td>There is no cost for the National Approval letter in Chile</td></tr>
<tr><td>Validation</td><td>15,000 – 50,000</td></tr>
<tr><td>Register</td><td>The EB of the CDM fixed the register price of a project according to tons of CO_2 reduced.
<table>
<tr><th>Average tons of CO_2e reduced per year during the crediting period</th><th>Cost (US $)</th></tr>
<tr><td>≤15,000</td><td>5,000</td></tr>
<tr><td>>15,000 ≤50,000</td><td>10,000</td></tr>
<tr><td>>50,000 ≤100,000</td><td>15,000</td></tr>
<tr><td>>100,000 ≤200,000</td><td>20,000</td></tr>
<tr><td>>200,000</td><td>30,000</td></tr>
</table>
</td></tr>
<tr><td>Verification and Certification</td><td>Monitoring : 0.05 – 5 % of the project value
Verification: 3,000 – 20,000 per verification visit</td></tr>
<tr><td>Certification and CERs issuance</td><td>There is an administration fee, and besides a fee for the Fondo de Adaptación en las Naciones Unidas, equivalent to 2% of the CERs annually generated.</td></tr>
</table>

Source (CNE, GTZ; 2007)

In Chile, there are dedicated financing funds for CDM projects. The funds from CORFO (Corporación de Fomento de la Producción) can be used to finance part of the CDM cycle for energy efficiency or renewable energy generation projects which are innovative or involve technology transfer. The CORFO's funds which are applicable to the CDM projects are the Fondo de Asistencia Tecnica (FAT), Fondo de Desarrollo e Innovacióon (FDI), Fondo Nacional de Desarrollo Tecnológico y Productivo (FONTEC), Proyectos Asociativos de Fomento (PROFO). (34) Also the program Todo Chile, within its section "Subsidios a estudios de preinversión o de asesorías especializadas en la etapa de preinversión", co-finances studies development of pre-investment or specialized consultancies in any of the pre-investment stages, specifically studies oriented to development of energy generation market from renewable sources; including those addressed to promote the project development for CDM. (6)

3.4.5 Monitoring

The carbon component of a mitigation project cannot acquire value in the international carbon market unless submitted to a verification process designed specifically to measure and audit the carbon component. Monitoring is a systematic observation of a project's performance by measuring and recording target indicators relevant to the objective of the project. The monitoring plan has to be transparent, reliable and relevant. (27)

The monitoring includes compilation and filing of all necessary data to measure or estimate the GHG emissions of the CDM project and for the calculation of the emission reductions resulting of the project. Monitoring must be done according to the Monitoring Methodology approved by the EB and must be activated when the operational phase of the project begins. (6) The parameters to be recorded are defined by the monitoring plan included in the PDD; these allow evaluating a posteriori the effective emission reductions estimated in the PDD. Monitoring cannot be neglected; it is a relevant factor in the generation of CERs. (34)

3.4.6 Verification/Certification

Verification is the periodic independent review and ex post determination by the DOE of the monitored reductions in anthropogenic emissions by sources of GHGs that have occurred as a result of a registered CDM projects activity during the verification period. It will include the periodic auditing of monitoring results, the assessment of achieved emission reductions and the assessment of the project's continued conformance with monitoring plan. The operational entity must make sure that the CERs have resulted according to the guidelines and conditions agreed upon in the initial validation of the project. Following a detailed review, an operational entity will produce a verification report and then certify the amount of CERs generated by the CDM project. (27)

Verification can also be defined as the periodic and independent test of the emissions reduction of the project. It is done by a different DOE in the case of the large scale project; in the case of small scale projects the same DOE which did the validation can perform also the verification. The CERs certification is the written form emitted from which a DOE assures to the EB that during the analyzed period of the project the emissions reductions have been achieved. The certification report is a request to the EB for the CERs expedition. Only after the approval of this report the CERs are emitted. (6)

3.4.7 Issuance of CERs

The EB must issue the CERs to the project partners within 15 days after the date of receipt of the request for issuance. As early as possible in the project design negotiations, contracts on carbon credit ownership must be made between the project participants. The rights and obligations of each participant should be clear. These rights could include the option to sell CERs to third parties. The contract should also specify the insurance coverage on the project and it should stipulate the rules for resolution of disputes between the parties. In addition two percent of the CERs issued must be paid to assist in meeting the costs of adaptation. The least developed countries are exempted from this fee. (27)

3.5 Project cycle duration

The duration of the project cycle has a direct relation with the development of each stage and the procedures established in them (See Table 4). An important factor which can reduce the required time is the existence of Baseline and Monitoring methodologies already approved by the EB, because the presentation of a new methodology begins a new administrative process by itself. The estimated times for a CDM project cycle are usually six and its duration can vary according the project itself. (6)

Table 4. Project Cycle Times

Stage of the project	Estimated times for each stage of the project	
	Without approved methodologies	With approved methodology
Design of the PDD	4 – 5 months (estimated)	2 months (estimated)
National Approval	The estimated time is 1 – 2 months, depending on the project type and its existing permissions.	
Validation	Minimum 5 months, plus more than 90 days as minimum for the approval of the proposed methodology	Minimum 5 months
Register	Without the request of the EB for an additional revision of the project, the registration last between 4 – 8 weeks. With revision, it can last around 6 months.	
Verification and Certification	The verification is an in situ evaluation process. The time required for it depends of the complexity and size of the project.	
CERs issuance	After sending the CERs issuance request, it normally takes 15 days for the EB to give an answer. Unless they ask for a review of the certification report.	

Source (CNE,GTZ; 2007)

There are considerable differences between a project which uses an approved methodology and those that propose a new methodology. As an average for the projects without an approved methodology, the project cycle could last around 18 months; while for the projects that use an approved methodology could last around 12 months.

3.6 Methodological Tools

In order to calculate the baseline scenario for the landfill project activities, the UNFCCC provides an approved consolidated baseline methodology ACM0001 called “Consolidated baseline and monitoring methodology for landfill gas project activities”.

This methodology is applicable to landfill gas capture project activities, where the baseline scenario is the partial or total atmospheric release of the gas and the project activities include situation such as:

- The captured gas is flared, and/or
- The captured gas is used to produce energy. Emission reductions can be claimed for thermal energy generation, only if the LFG displaces use of fossil fuel either in a boiler or in an air heater. From claiming emission reductions for other thermal energy equipment, project proponents may submit a revision to this methodology
- The captured gas is used to supply consumers through natural gas distribution network. If emissions reductions are claimed for displacing natural gas, project activities may use approved methodology AM0053.

This methodology refers to the latest approved version of the tools:

- "Tool for the demonstration and assessment of additionality"
- "Tool to determine project emissions from flaring gases containing methane"
- "Tool to calculate baseline, project and/or leakage emissions from electricity consumption"
- "Combined tool to identify the baseline scenario and demonstrate additionality"
- "Tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site"
- "Tool to calculate the emission factor for an electricity system"

4 METHODOLOGY

4.1 Review of the landfills on the Metropolitan Region of Santiago de Chile and the possible, or actual, biogas generation and use.

During the first part of the investigation, the main objective was to compile data about the current situation of the landfills of the MR of Santiago de Chile and the current waste management. In order to achieve this objective it was necessary to make an extended literature review and also to interview different representatives of diverse Chilean organisms, in order to understand the function of them and also to recognize the organization around the waste management area. As well as the possibilities of support and the facilities for the CDM projects; the local perspective of the landfill gas use and its possibilities. The organizations interviewed are all located in Santiago de Chile, these were:

a. IASA – Ingeniería Alemana S.A.
b. ProAmbiente
c. CONAMA – Comisión Nacional del Medio Ambiente
d. KDM – visit to the landfill installations of Loma Los Colorados
e. CONAMA – Unidad de Cambio Climático/Departamento de Estudios
f. EcoMaule – visit to the landfill installations
g. Consorcio Santa Marta – Visit to the landfill installations of Santa Marta
h. CORFO – Chilean Economic Development Agency
i. CONAMA – Departamento de control de la contaminación
j. ProChile – Medio ambiente y calidad
k. Centro de energías renovables – CORFO

Most of the information of the landfills was the result of the visits to their installations, in the case of missing information in situ, the source is specified in the next chapter. Also it was necessary to do an extended literature review to compile the necessary data for the calculations. All the photos of the landfills were also taken directly in the mentioned places.

4.1.1 Calculation of the methane generation

Methane generation in landfills is generally modeled using a first order kinetic equation based on waste amount over time, waste composition and other factors. In first order models, methane production is assumed to be in a steady, linear decrease over time proportional to the degradation of organic matter in any given year and the remaining fraction of organic matter from previous years. Each year´s waste follows a decreasing exponential trend in gas production until it is completely degraded. According to these model assumptions, a gradual decline in landfill gas would occur post-closure. Although the first order models have the same basic component with slight differences, their outputs vary considerably. (36)

The required data to calculate the biogas generation yield of the MR landfills was obtained through the literature review in situ, visits to two of the three landfills and the different interviews. After reviewing and comparing the information, one source was chosen for the calculations of each landfill as follows:

- The Resolución de Calificación Ambiental 2009 for the landfill Santa Marta and its expansion of the biogas burning gas. (37)
- The Project Design Document of Loma Los Colorados Landfill Gas Project. (38)
- The Declaración de Impacto Ambiental of the system of capture and biogas burning of Santiago Poniente. (37)

According to Thompson et al. 2009 no calculation model matches perfectly the methane recovery data but some models fare better than others. To get this result different calculation models, German EPER, TNO, Belgium, LandGEM, and Scholl Canyon, were compared basing in the methane recovery rates of 35 Canadian landfills; for the comparison two different fractions of degradable organic carbon (DOC_f) were used. As result of this comparison the Belgium, Scholl Canyon, and LandGEM v. 2.01 models produced the best results of the existing models with their respective mean absolute errors. (36)

With the reference of this study the LandGEM version 3.02 was chosen to be compared with another first degree calculation equation, Weber & Doedens.

4.1.2 Weber & Doedens model

In German speaking countries two models are used model of Weber and of Tabasaran / Tettenberger. For this analysis the model of interest is the Weber model (39):

$$Q_{a,t}\left[\frac{Nm^3}{year}\right] = 1868 \cdot M \cdot TOC \cdot f_{a0} \cdot f_a \cdot f_0 \cdot f_s \cdot k \cdot e^{-k \cdot t}$$ **Eq. (1)**

Where:

$Q_{a,t}$ = Total production of landfill gas (Nm^3/year)

M = Amount of waste disposed in the landfill (ton)

TOC = Total Organic Carbon in the waste (kg/ton)

f_{a0} = Initial losses factor, this is the fraction of organic carbon lost during the first aerobic fermentation phase. Constant values between 0.7 and 0.9.

f_a = Decomposition factor, it considers the landfill management technology, specially the compactation and daily covering. Constant value proximately 0.7.

f_0 = Optimization factor (percentage of organic carbon which becomes landfill gas (CO_2+CH_4), constant value of approximately 0,7

f_s= Captation rate, recommended constant 50%

k = Degradation rate ($year^{-1}$), recommended value 0.05

T = Time (years)

This calculation model is based in the biogas generation from the amount of disposed waste in the landfill and the use of external factors as the operation, quantity of biodegradable material. This model represents an improvement of the Tabasaran model and is applicable for a landfill case, this method considers a characterization of USW in dry basis, and therefore it considers humidity differences. (40)

To compare the obtained results, a third model was elaborated based on the "Methodological tool to determine methane emissions avoided form disposal of waste at a solid waste disposal site" which calculates the baseline emissions of CO_2e of the landfills according to the CDM and the UNFCC regulations.

4.1.3 Clean Development Mechanism Methodological Tool:

The "tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site" calculates baseline emissions of methane from waste that would in the absence of the project activity be disposed at solid waste disposal sites (SWDS). The tool is applicable in cases where the solid waste disposal site where the waste should be dumped can be clearly identified. (41)

The tool provides procedures to determine the methane emissions avoided during the year *y* from preventing waste disposal at the solid waste disposal site during the period from the start of the project activity to the end of the year *y* in tCO_2e ($BE_{CH4,SWDS,y}$). The calculation is based on a first order decay model, the model differentiates between the different types of waste *j* with respectively different decay rates k_j and different fractions of degradable organic carbon (DOC_J). The model calculates the methane generation based on the actual waste streams $W_{j,x}$ disposed in each year *x*, starting with the first year after the start of the project activity until the end of the year *y*, for which baseline emissions are calculated. (41)

In cases where at the SWDS methane is captured (e.g. due to safety regulations) and flared, combusted or used in another manner, the baseline emissions are adjusted for the fraction of methane captured at the SWDS. The amount of methane produced in the year *y* ($BE_{CH4,SWDS,y}$) is calculated as follows:

$$BE_{CH4,SWDS,y} = \varphi \cdot (1-f) \cdot GWP_{CH4} \cdot (1-OX) \cdot \frac{16}{12} \cdot F \cdot DOC_f \cdot MCF \cdot \sum_{x=1}^{y} \sum_j W_{j,x} \cdot DOC_j \cdot e^{-k_j \cdot (y-x)} \cdot \left(1-e^{-k_j}\right) \quad \textbf{Eq. (2)}$$

Where:

$BE_{CH4,SWDS,y}$ = Methane emissions avoided during the year *y* from preventing waste disposal at the solid waste disposal site (SWDS) during the period from the start of the project activity to the end of the year y (tCO_2e)

ϕ = Model correction factor to account for model uncertainties (0.9)

f = Fraction of methane captured at the SWDS and flared, combusted or used in another manner

GWP_{CH4} = Global Warming Potential (GWP) of methane, valid for the relevant commitment period. Decisions under UNFCCCC and the Kyoto Protocol a value of 21 is to be applied for the first commitment period of the Kyoto Protocol

OX = Oxidation factor (reflecting the amount of methane from SWDS that is oxidized in the soil or other material covering the waste) Use 0.1 for managed solid waste disposal sites that are covered with oxidizing material such as soil or compost. Use 0 for other types of solid waste disposal sites.

F = Fraction of methane in the SWDS gas (volume fraction) (0.5) This factor reflects the fact that some degradable organic carbon does not degrade, or degrades very slowly, under anaerobic conditions in the SWDS. The default value is recommended by IPCC.

DOC_f = Fraction of degradable organic carbon (DOC) that can decompose. IPCC default 0.5

MCF = Methane correction factor, accounts for the fact that unmanaged SWDS produce less methane from a given amount of waste than managed SWDS, because a larger fraction of waste decomposes aerobically in the top layers of unmanaged SWDS. Use 1.0 for anaerobic managed solid waste disposal sites, use 0.5 for semi-aerobic managed solid waste disposal sites, use 0.8 for unmanaged solid waste disposal sites-deep and/or with high water table, use 0.4 for unmanaged-shallow solid waste disposal sites.

$W_{j,x}$ = Amount of organic waste type *j* prevented from disposal in the SWDS in the year *x* (tons)

DOC_j = Fraction of degradable organic carbon (by weight) in the waste type *j*. According to the waste type are the different values to take into account of the percentage of DOC_j in wet and dry waste. For more detailed information see "tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site" To calculate the fraction of degradable organic carbon it is necessary to have the waste type composition, the percentage of dry content in the fraction of waste and the quantities of waste in a specific year. The source of the waste composition for the specific case of the MR of Santiago is (CONAMA,2007). The year used as base was the first year of Santa Marta Landfill corresponding to 2002. Finally the DOC_j is the sum of the partial DOCs of each waste type, which vary according the percentage of it in the total waste and its individual percentage of DOC according the values given in the tool.

k_j = Decay rate for the waste type *j*. The values of k_j are specified according to the temperature and climate conditions, and also according the waste type and its degrading rate. For more detailed information see "tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site". To calculate the total decay rate for the waste of the landfills the waste composition was necessary and was multiplied by the values of k assigned in the tool to each type of waste according the local conditions of climate and temperature, finally the sum of all the partial values is the total k of the waste.

j = Waste type category (index)

x = Year during the crediting period: x runs from the first year of the first crediting period (x=1) to the year *y* for which avoided emissions are calculated (x = y)

y = Year for which methane emissions are calculated

Calculation of methane emissions avoided was done from the year 2002 to the year 2006 in order to have the same period of time calculated for all the landfills. This means that it is supposed that the crediting period of the baseline methodology begins in 2002 for the three cases.

4.1.4 LandGEM

LandGEM is a tool created by U.S. Environmental Protection Agency to estimate emission rates for total landfill gas, methane, carbon dioxide, non-methane organic compounds (NMOCs), and individual air pollutants from MSW landfills. LandGEM can use either site-specific data to estimate emissions or default parameters if no site-specific data are available. The model was developed by the Control Technology Center (CTC) of the U.S. EPA and it is available online. (42)

LandGEM is based on a first-order decomposition rate equation for quantifying emissions from the decomposition of landfilled waste in MSW landfills (See Eq. 3), because of the data available for landfills are limited; the use of a more sophisticated calculation method is not justified. The software provides a relatively simple approach to estimation landfill gas emissions. Model defaults are based on empirical data from U.S. landfills. Field test data can also be used in place of model defaults when available. (42)

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} kL_0 \left(\frac{M_i}{10}\right) e^{-kt_{ij}} \quad \textbf{Eq. (3)}$$

In order to estimate the emissions from a landfill LandGEM needs information about: (42)

- The waste design capacity of the landfill
- The amount of waste-in-place in the landfill or the annual waste acceptance rate for the landfill
- The methane generation rate (k)
- The potential methane generation capacity (L_o)
- The concentration of total non-methane organic compounds (NMOCs) and speciated NMOCs found in the landfill gas
- The years the landfill has been in operation
- Whether the landfill has been used for disposal of hazardous waste (co-disposal)

In order to obtain the values of the methane generation rate (k) the formula (36)

$$k = 3.2 \times 10^{-5}(x) + 0.01 \quad \textbf{Eq. (3)}$$

Where *x* represents the annual average precipitation from 1971 to 2006 for province where the landfill is located. According to the Dirección Meterológica de Chile this value is 312.5 mm. (43)

As result of the equation the value of **k = 0.019**

The value of the Degradable organic carbon was also necessary for the LandGEM calculations; this quantity was calculated with the equation

$$DOC = (0.4 \times A) + (0.17 \times B) + (0.15 \times C) + (0.3 \times D) \qquad \textbf{Eq. (4)}$$

With all units in wet weight (w/w) of kg carbon/kg of waste.

Where:

DOC = degradable organic carbon

A = fraction of municipal solid waste that is paper and textiles waste

B = fraction of MSW that is garden or park waste

C = fraction of MSW that is food waste

D = fraction of MSW that is wood or straw waste

It was also necessary to calculate the methane generation potential, based on the equation following equation (36) and with the calculated value of DOC mentioned above.

$$L_o = F \times DOC \times DOC_f \times \frac{16}{12} \times MCF \qquad \textbf{Eq. (5)}$$

Where:

MCF = Methane correction factor (fraction, default = 1.0)

DOC = Degradable organic carbon (kg/ton)

DOC_f = Fraction of assimilated DOC (according to IPCC 1996 = 0.77; IPCC 2006 = 0.5)

F = fraction of methane in landfill gas (0.5 default)

16/12 = stoichiometric factor

According the equation the obtained quantity was **Lo = 0.06254**

Once these values were calculated the next step was to use LandGEM with the different landfill cases and calculate the landfill gas generation for each case.

4.2 Use possibilities

For the calculation of electricity generation with the biogas of the landfills, the amount of biogas consumed as well as the capacity of electricity production was based in the case of the landfill Lomas Los Colorados. The engines used in this landfill are 12 cylinder engines of 1MW of generation capacity, these engines count with technology for low emissions of mono-nitrogen oxides (NOx) and CO, and their designed to work with low calorific power fuels. According to the Declaration of Environmental Impact (DIA in Spanish) of Lomas Los Colorados this engines have a consumption of 550 m^3/h of biogas in order to produce, the efficiency of the engines is 35% and they have a yearly operation of 8208.12 hours.

5 ACTUAL CONDITIONS IN SANTIAGO DE CHILE

Chile is located occidental and southern of South America (Figure 5) its surface is 2.006.096 km^2, without its territorial sea, the Exclusive Economic Zone and the continental platform. Its length, from the Línea de la Concordia to the Antarctic Pole is superior to 8.000 km. (44)

Chile borders at North on Peru through the Línea de la Concordia; at east on Argentina and Bolivia; at South on the South Pole and at West on the Pacific Ocean. According to the XVII National Census of Population and VI of Housing, made in April 2002, the population of Chile is 15.116.435 inhabitants, from which 13.090.113 live in urban areas and only 2.026.322 in rural areas. The national population raised 13,2% regarding the numbers in 1992. (45)

Figure 5. Chile

The most representative economical activities of the country belong to the natural resources exploitation; the copper mining, forestry of wood and cellulose, fishing and agriculture are the main generators of the gross domestic product. (45)

The political division of the country consists of 15 regions divided in 53 provinces and 346 municipalities, called communities. (46) Chile is a united and democratic country, governed by a presidential system. The Political Constitution establishes the division of the three independent powers of the State in Executive, Legislative and Judicial. (47)

The President of the Republic, elected every four years through direct vote and absolute majority, exerts the Government and the State administration. The President can make, sanction and promulgate laws, he has also the legal authority to designate and remove the ministers of his cabinet. Another duties of the president are to name the maximum authorities of the internal government of Chile; the mayors of the 15 regions and the governors of the 53 provinces. (47)

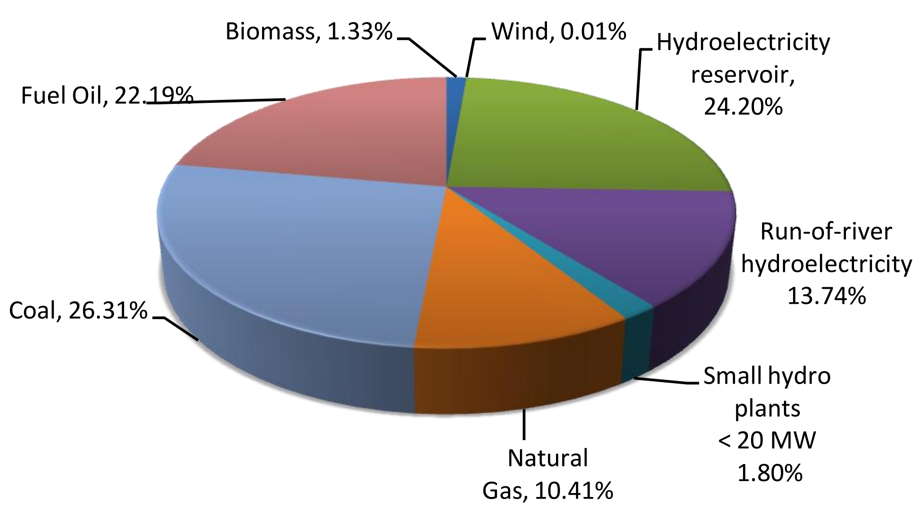
The Metropolitan Region of Santiago (MR) has the highest urban population of the country, with 5.875.013 inhabitants, which represents 39% of the total population of Chile. The population density is also the highest in the MR of Santiago with 393,5 inhab/km^2, followed only by the regions of Valparaíso with 93,9 inhab/km^2 and Bío-Bío with 50,2 inhab/km^2. In a ten years period, between 1992 and 2002, the urban population increased 17,5% and the rural population decreased 8,2%. (45)

The MR is located between the 32°55' and 34°19' South latitude and between the 69°46' and 71°43' West longitude. It is the smallest region of Chile and its capital is the city of Santiago, which is also the capital city of the nation. According to the Military Geographic Institute the MR has a surface of 15.403,2 km^2, which represents a 2,04% of Chile. (45)

5.1 Energy

By the end of 2007 the installed capacity for energy generation in Chile was 12.848 MW, taking into account only the power stations of public service; during the same year the electricity generation was 57.222 GWh, from which 40% came from hydroelectric plants. (48) In 2007 the generation of electricity (See Figure 6) was distributed among hydroelectric power plants (38%), natural gas (10%), coal (26%), fuel oil (22%) and non-conventional renewable energy (3,1%). (49)

Figure 6. Electricity Generation by Source 2007



(CNE/GTZ, 2009)

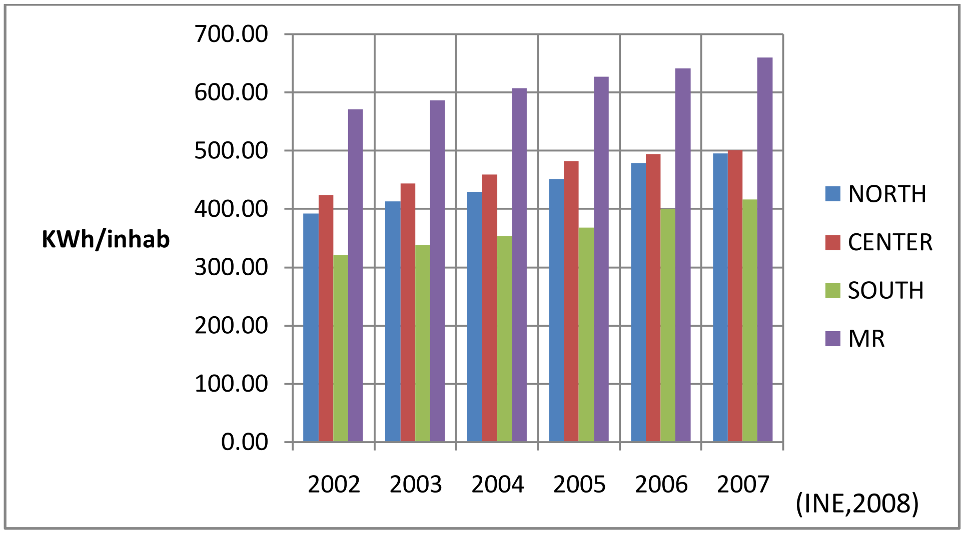
Between 1997 and 2007 the final consumption of energy grew an average of 2.8% yearly, while the electric consumption increased near to an average 6% yearly, indeed the growth of the energy demand has followed the growth of the Gross National Product (GNP). (50)

The final consumption of energy in Chile is defined by four big sectors: (50)

- Transport is the biggest consumer with a 35% of the final consumption, focused on the oil by-products.
- Industry, which represents a 23% of the final consumption, demands a variety of resources but its 83% of consumption is mainly focused on oil by-products, electricity and biomass.
- Mining only means a 13% of the final consumption of energy and electricity is the main source of this area.
- Commercial-public-residential area which represents a 25% of the final consumption of energy. The main fuel of this sector is wood used for cooking and heating.

The electricity consumption, in relation with the main sectors, shows the MR as the biggest consumer in the national context with a 29.28%; a significant part of its consumption is focused in the Commercial-Public-Residential area. The per capita consumption in the country raised a 51% in a period of time from 2002 to 2007 (See Figure 7), in contrast with the other regions of the country the MR has the biggest per capita consumption of electricity. (48)

Figure 7. Residential consumption per capita



5.1.1 Non Conventional Renewable Energies

In 2008 was created the Program of Support for the Development of Non Conventional Renewable Energies (NCRE), in order to remove the obstacles for the development and promotion of these technologies. The budget was of approximately 2.500 million of Chilean pesos, the first year, and it was expected to grow to more than 4.100 millions in 2009 in order to add two new work lines: design and implementation of a center of renewable energies; the installation of NCRE to provide energy to schools and rural places. (50)

5.2 Environmental Policies and Regulations

In 1994 the law of Environmental Basis N° 19.300 was published. The existing and future regulations in the environmental area are based on this law. The Environmental Basis law establishes, among other things, the right to live in a pollution free environment, the protection of the environment, nature and the natural patrimony. (51) Because of the law 19.300 the National Environmental Commission (CONAMA in Spanish) is created as a public service; which main functions are to propose environmental policies to the president of the republic, to inform about the accomplishment and application of the environmental regulations, administrate the environmental impact evaluation system (SEIA in Spanish), as well as the process of elaboration of regulations of environmental quality and emissions, and act as an organism of consulting, analysis, communication and coordination in environmental issues. (52)

After all the work done in the country in order to create a framework for the adequate environmental management, in January 2010 the law N° 20.147 is published. The law creates the Department of Environment, the Service of Environmental Evaluation and the Supervision of Environment. (51) With the creation of new organisms and regulation the waste management conditions have changed in Santiago.

5.2.1 Policy of integral management of solid waste

The policy of integral management of Solid Waste (SW), approved by the directive board of CONAMA the January 17th, 2005, establishes concrete actions in a short term, with the people responsible and dates for its implementation, as well as working parameters in medium term. The main objective of the policy is to reach a SW management which represents the minimum risk to the public health and the environment; at the same time to favor an integral vision, which assures the sustainable and efficient development of the waste management sector. (53)

The policy also has among its goals to minimize the sanitary and environmental risks consequence of the inadequate SW management; also to generate and promote a public service of Domiciliary Solid Waste (DSW) management which keep an adequate quality and with costs oriented prices. It proposes to foment a regional vision for the DSW management and favors the development of efficient and dynamic markets for the waste management, this through the promotion of a minimization culture. Finally it attempts to promote the environmental education, the civic participation and a higher conscience regarding the waste management; to build and implement information systems of the SW and to generate a modern and efficient institutional framework for the SW management. (53)

In order to achieve its objectives the policy has established its own guidelines per each objective which it has; some of those are to complement the current regulations, take care of polluted places generated by the inappropriate waste management, improve the bidding processes, set up the competence of the municipalities and regional governments in the DSW management, which will be projected through Management Plans; also to stimulate the market and implement a minimization strategy, the promotion of the formal and informal education on waste management and to stimulate the citizen participation in the adequate management of the waste which they generate, create information systems for the SW management and create an institutional coordinated system. (53)

Since the publication of the policy the Chilean government works with most of its objectives, those planned in short term are almost completely finished and those in long term are foreseen to be done during this year. Some examples of the fulfillment of part of this policy are the Regulation of Basic Sanitary and Safety Conditions of the Landfills as well as the Regulation for the Management of Sludge Generated in Sewage Treatment Plants. The current and future years are of big meaning in the waste sector because they mean a time of changes and adaptations, at present is possible to see some of these changes already applied or in the implementation phase.

5.2.2 Regulation of Basic Sanitary and Safety Condition of the Landfills

In August 18th 2005 the Regulation of Basic Sanitary and Safety Conditions of the Landfills was promulgated and in January 5th 2008 published in the Official Journal. This means that from 2008 all the new landfills should accomplish the new dispositions and the operating sites should improve their conditions to adapt themselves to the new regulations. The existing facilities had a year to update their infrastructure and processes, at present some of those already existing facilities are still working in their improvements. (54)

The regulation answers the necessity of a modern and efficient regulation for the evaluation and management of the landfills in Chile, in order to avoid sanitary or environmental emergencies, with no importance if these landfills are under public or private administration.

This new regulation stipulates the basic conditions for the landfills, such as the requirements for the project, for example an adequate engineering design which includes the adequate background and definitions, together with other features like a projection of the users population, the technical and calculation memo, amongst others. Other aspects taken into account are for example: the obligation of an impermeable coating on the bottom of the landfill, a system for the treatment of the leachates, the size of the cells, the biogas recovery system as well as the perimeter conditions in order to avoid the unauthorized and uncontrolled entrance of people and animals, among other factors. (54) The new regulation, for the design and management of the landfills, is focused in the improvement of the service and the future reduction of waste disposal facilities. As examples of the application of this regulation are the three landfills of the MR of Santiago, the landfills fulfill most of the requirements of the current directive and satisfy the service necessity of the area.

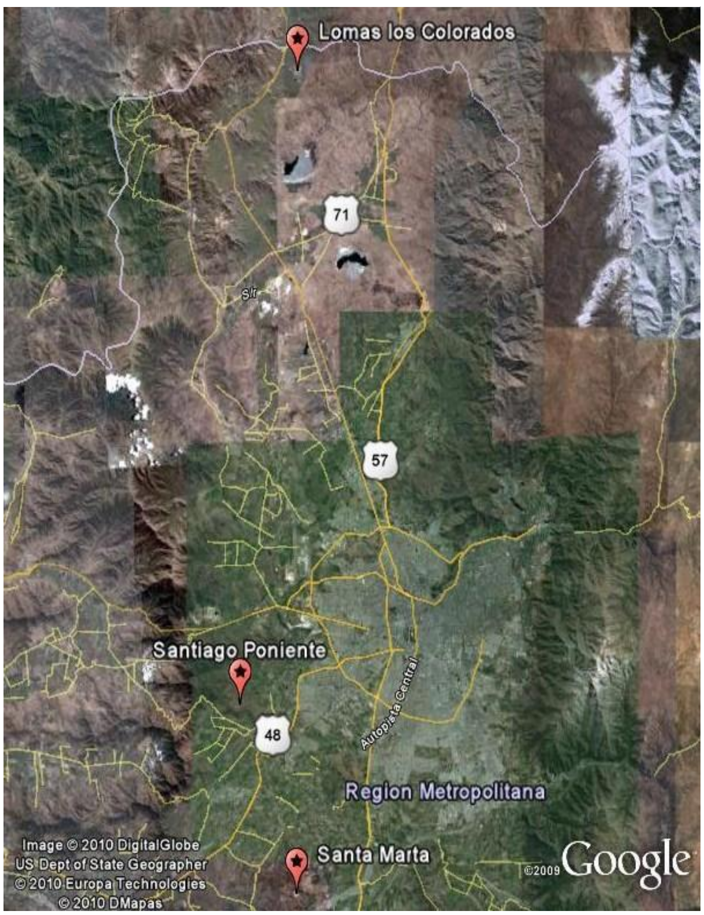
5.2.3 Organizations

There is also an important group of institutions and councils, which were recently created, in charge of the promotion of the new waste management policies. For example the Clean Production Council (Consejo de Producción Limpia, CPL in Spanish) which works as an assessor and host of dialogue between the public sector, companies and workers, its main goals are to communicate and establish an environmental perspective focused in the prevention of pollution instead in final control of the waste. The CPL was created in December 2000 by the agreement N° 2091/2000 of the Council of the Corporation of Production Promotion (CORFO in Spanish). Among the main activities of the CPL are to follow the application of the Clean Production Policy, which the council wrote; as well as to use the Clean Production Agreement, which also are creation of the council, as an instrument of innovation, promotion and financing of projects which mean an improvement of the production processes and a reduction of the waste generation within them. All these have the support of different workshops which focus on the formation of human resources at local and regional level. (55)

6 RESULTS

According to CONAMA in the year 2008 an amount of 5.714.051 tons arrived to a final disposal facility in Chile. Approximately the 65% of the total amount of waste arrived to a proper landfill, for the year 2010 the projections suggest a total generation of 4.421.239 tons. It is important to mention that without the MR the quantities of waste decrease considerably, for the year 2008 the waste disposed, without the MR was 3.015.035 tons and the amount for the MR the same year was 2.699.016 tons. That is almost the same quantity of the rest of the country. (56)

Figure 8. Landfills in the MR



In Santiago de Chile in 1997 the waste generation per capita was of 0,87 Kg per inhabitant per day and for the year 2005 it grew up to 1.18 Kg per inhabitant per day. (3) According to the latest record of CONAMA the Production Per Capita in 2006 was of 1.11 in the MR. Although this number seem to be lower, it is important to take into account that it consider not only the production of Santiago, but all the other provinces that form the MR which are altogether: Chacabuco, Cordillera, Maipo, Melipilla, Santiago and Talagante. According to the last census of 2002 the population of the region was 6,061,185 inhabitants, representing 40.1% of the total population of Chile. (45)

In 2008 the total amount of MSW, registered by CONAMA, was approximately 2,699,016 tons. From this amount almost the 99% arrive to a proper final disposal facility also called landfills. According to the projections of CONAMA the waste production per capita in 2008 is 1.105 kg/inhab/day (56) Nowadays there are three facilities for the final disposal of the USW in the MR of Santiago (See Figure 8); these are the landfills Lomas Los Colorados, Santiago Poniente and Santa Marta. (4)

6.1.1 Landfill Lomas Los Colorados

Lomas Los Colorados (LLC) replaced the landfill of Cerro de Renca located north of Santiago. This landfill is administrated by KDM S.A., operates since June 1996 and has its Environmental Qualification Resolution (Resolución de Calificación Ambiental, RCA in Spanish), it is important to mention that Lomas Los Colorados got voluntarily into the Environmental Impact Evaluation System (Sistema de Evaluación de Impacto Ambiental, SEIA in Spanish) in 1995 and it was one of the first projects to be evaluated under these regulations. Its approval came out on 27th June 1995 under the Environmental Qualification Resolution No. 990. It is planned to operate around 50 years, in dependence of the volume of waste deposited, located in the community of Til-Til Km 63,5 route 5 North, in front of the locality of Montenegro. (9)

The project of LLC has 600 hectares surface, 210 hectares belong to the final disposal of waste. Nowadays it is designed to receive 150 thousand tons of waste per month and the dump area is divided in 24 cells. (9)

According to KDM S.A. the landfill has a total surface of 800 hectares and 120 hectares are designated to the final disposal of waste. The landfill still counts with 40 more operational years.

LLC serves the communities of Cerro de Navia, Colina, Conchalí, Curacaví, Estación Central, Huechuraba, Independencia, La Cisterna, La Reina, Lampa, Las Condes, Lo Barnechea, Lo Prado, Maipú, Ñuñoa, Providencia, Pudahuel, Quilicura, Quinta Normal, Recoleta, Renca, San Joaquín, San Miguel, Santiago, Tiltil and Vitacura. In 2008 the amount of MSW disposed in LLC was 1.490.865 tons, this meant approximately the 58% of the annual total of MSW received. (56)

This landfill has a transference station in which the collector trucks recollect the waste directly from the communities. The first step in the transference station is to weight the collector trucks; subsequently the content of the trucks is delivered into silos to be compressed. (See Figure 9)

Figure 9. Transference station

(Quilicura, Chile; Godoy, Enma; 11.03.2010)

There are 162 operative silos; each silo can take between 25 to 30 tons of compressed waste, there are in total 14 deposit positions for the silos and collector trucks. A train transports the filled silos to the landfill, it transports 25 silos per journey and makes 10 journeys per day; as a total there are transfer approximately 6.000 tons per day from the transfer station to the landfill (See Figure 10). Approximately 62% of the waste received in the landfill is domiciliary and 24 communities in the MR deliver their waste there.

Figure 10. Transportation train

(Quilicura, Chile; Godoy, Enma; 11.03.2010)

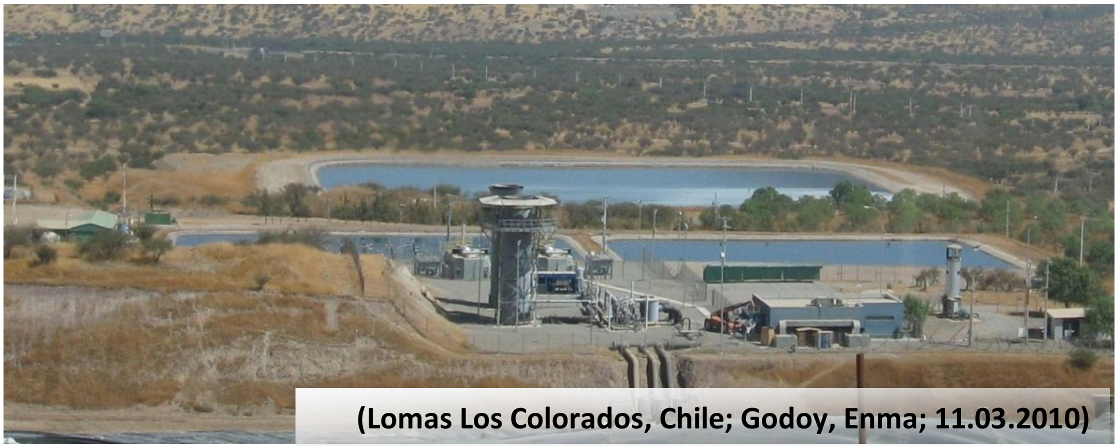
The landfill gas recollecting system initially had a burning torch; the system improved to two new flaring torches (See Figure 11) and entered the CDM because of the carbon dioxide reduction that these meant. Nowadays the biogas recollecting system has 210 wells and 80 “punteras”, which are smaller wells and a less depth than the normal wells.

The efficiency of collection of the biogas is 50%; the efficiency is based on theoretical models, which compare the amount of gas collected with the calculation of gas obtained from the quantity of waste within the landfill. In middle of 2010 two electricity generator engines were installed, with capacity of generating 1 MW each one. The torches burn 5.000 m^3/hr of biogas when the two engines are working properly, when the engines are not working the torches burn approximately 7.000 to 8.000 m^3/hr of Landfill Gas. In order to preserve the engines and eliminate the Oxiloxan of the gas there is a cleaning system, which works with temperature and pressure differences to condensate the unnecessary substances in the gas; it is possible to obtain a major concentration of methane in the gas if they use other cleaning processes, but that would increase the investing costs. The engines have an efficiency of 35% and consume 550 m^3/hr, the installed capacity of each engine is 1 MW. In Figure 12 it is possible to see the installation for the torches, generator engines and the leachates treatment pools.

Figure 11. Flaring torches

(Lomas Los Colorados, Chile; Godoy, Enma; 11.03.2010)

Figure 12. Treatment facilities



(Lomas Los Colorados, Chile; Godoy, Enma; 11.03.2010)

The number of electricity generator engines will grow to 14 more increasing the reduction of emissions because of the substitution of non-renewable sources of electricity generation. Another studies were done before making the decision of generating electricity, for example the possibility of injecting the gas directly to the local grid, but the requirements for the quality of the gas in the grid make the project to expensive to be done.

6.1.2 Landfill Santa Marta

The second largest landfill in the MR managed by the Consorcio Santa Marta and like the new projects possesses its RCA; the landfill began functions in April 2002 replacing the landfill Lepanto. It is managed by the company Consorcio Santa Marta S.A. (CSM), the contract signed give the company a concession of 20 years. (57) It is located 12,5 Km from Route 5 South in the community of Talagante, but their access are through San Bernardo. It is designed to receive a maximum of 60.000 tons per month of Domiciliary or Utilizable Solid Waste. The surface of the facilities of the landfill has 296 hectares and the area destined to the final disposal of the SW is 77 hectares. (9) In 2006 it received approximately 48.600 tons of SW per month and had accumulated by that time 2.332.857 tons of SW.

The landfill Santa Marta serves the communities of: Buín, Calera de Tango, El Bosque, El Monte, La Florida, La Granja, La Pintana, Lo Espejo, Macul, Paine, Pedro Aguirre Cerda, Pirque, Puente Alto, San José de Maipo, San Ramón and Talagante. All the communities are part of the MR and in 2008 delivered to Santa Marta 734.128 tons of MSW, which meant approximately a 29% of the total amount of waste of the MR that year. (56)

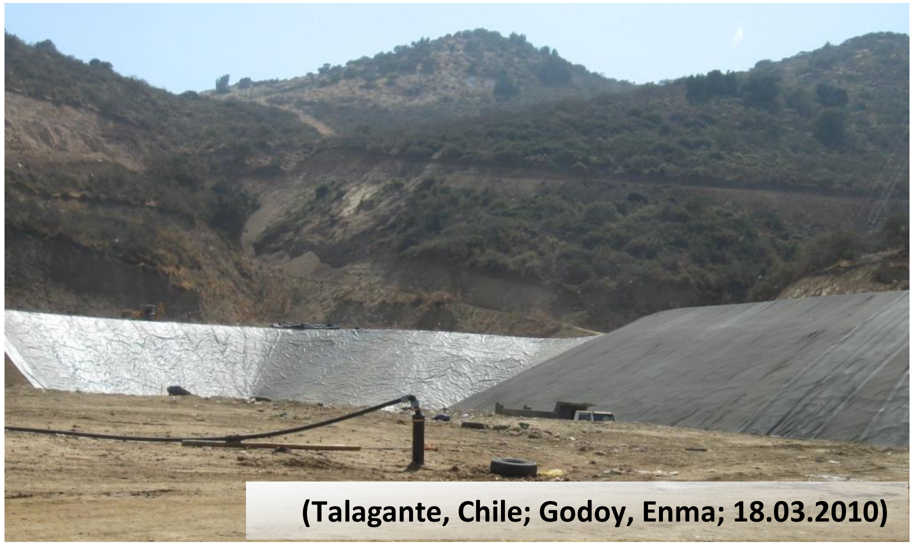
The landfill Santa Marta has a transfer station, in which the collector trucks unload the waste into larger trucks, without any kind of compacting or waste selection. According to the RCA 966 the trucks, which take the waste to the landfill, should accomplish certain requirements, like for example to avoid the leakage of leachates. The landfill is located into a ravine and it works filling it (See Figure 13).

Figure 13. Santa Marta Landfill

(Talagante, Chile; Godoy, Enma; 18.03.2010)

As the regulations declare has, an impermeable cover to avoid the leakage of leachates into the ground, the landfill also use old tires as protection for the coating. There is a gas recovery system that recollect and burn approximately 6.500 m^3/hr of landfill gas per year, the biogas recollection is still low because there are a lot of temporary wells, but during the life of the project is expected to make them permanent and to increase the capitation efficiency. At the present time the landfill has 198 permanent and 8 temporary wells, which means a total of 206. (See Figure 14)

Figure 14. Permeable coating and gas collecting well



The burning system has horizontal flame equipments, each one burn approximately 4.427 m^3/hr of gas (See Figure15). These equipments have a forced cooling system for the flames that cool the flames from 1.200 to 400 °C, the advantages of this system is that it reduces the NOx emissions. Due to the higher position of the burning system, it does not need a cleaning system for the gas because the undesirable particles stay on the lower level and does not reach the torches.

In the near future the landfill will add a vertical torch due to the requirements of the Plan for Prevention and Decontamination of the Atmosphere for the Metropolitan Region (PPDA), which establishes a limit of 100 ppm of CO with a correction of 3% of O_2. Although the actual torches reduce the NOx they do not reach the CO levels stipulated in the PPDA.

Figure 15. Horizontal flame torches


(Talagante, Chile; Godoy, Enma; 18.03.2010)

The leachates treatment system has a third treatment through eucalyptus trees. After two first treatment phases there is a third treatment face with a drip irrigation system, which takes the water to eucalyptus trees and they do the third treatment naturally.

Santa Marta has joint the CDM in 2006 with the “Santa Marta Landfill Gas (LFG) Capture Project” and nowadays sells the CERs obtained through the burning of the biogas. They do not use the gas for other processes.

The methodology applied to the project was the ACM0001 “Consolidated baseline methodology for landfill gas project activities”. Version 04, 28 July 2006. (57) They used US EPA LANGEM to calculate the future GHG emissions of the landfill.

6.1.3 Landfill Santiago Poniente

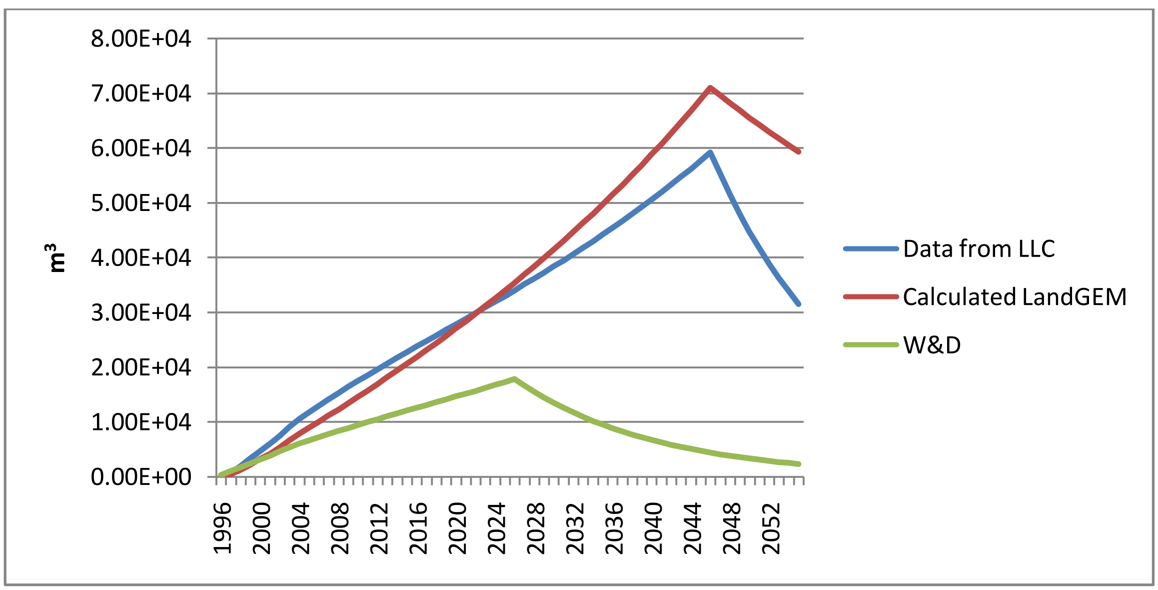
This landfill began operations in October 2002. Its impermeable surface is around 35.000 m^2, on which the waste is disposed; the total surface of the landfill is 57.3000 m^2. Santiago Poniente is located in Fundo la Ovejería de Rinconada of Lo Vial in the community of Maipú. (9) The land used by the landfill is located in the latitude 33°31’00” South and in the longitude 70°52’30” West at 40 meters above the sea level. (58) It can receive approximately 40.000 tons of DSW per month. (9)

According to CONAMA, the landfill serves to only nine communities of the MR: Calera de Tango, Cerrillos, Estación Central, Isla de Maipo, Padre Hurtado, Pedro Aguirre Cerda, Peñaflor, Peñalolen and San Bernardo; in 2008 these communities delivered to Santiago Poniente approximately 334.568 tons of SW, which were then a 13% of the total waste production of the MR.

6.2 Calculation results

From the application of the LandGEM model, the projections of landfill gas emissions for the three landfills are presented in the following graphics. As a result of the comparison between the models; LandGEM, Weber&Doedens and CDM methodological tool; the following results for the comparison of the models and the landfill gas generation were obtained. (See Figure 16) As mentioned in the methodology, the amounts of waste used to calculate the landfill gas emissions are based in different sources per each landfill. For the comparison of models the base was the case of the landfill Lomas Los Colorados (LLC), its waste amounts (past and future) and the charts given in the Environmental Impact Declaration of the landfill.

Figure 16. Model comparison



(Sources: Elaborated model, LandGEM, based on Environmental Impact Declaration of LLC, 2006)

LandGEM was selected based on Thompson et al. 2009 whom mention that most of the models underestimate the generation potential of the landfills. The study "Building a better methane generation model: Validating models with methane recovery rates from 35 Canadian landfills" compares five estimating methane production models to methane recovery rates for 35 Canadian landfills, assuming a recollection of 80% of the landfill gas. The Belgium, Scholl Canyon, and LandGEM ver. 2.01 models produced the best results of the analyzed models with respective mean absolute errors compared to methane generation rates of 91%, 71% and 89%. (36) Together with the fact that US EPA has extended academic support and bases, which Weber and Doedens did not, because during the investigation was rather difficult to find a detailed explanation of the model and its background.

6.2.1 Lomas Los Colorados

LandGEM model uses a first order decomposition rate equation for quantifying emissions from the decomposition of landfilled waste in Municipal Solid Waste landfills. (42)

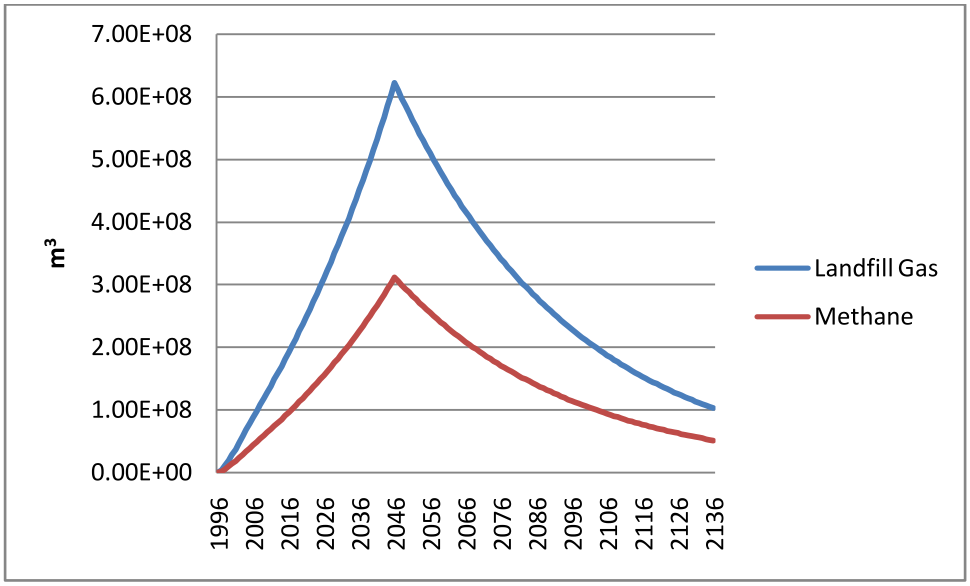
$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} k L_0 \left(\frac{M_i}{10}\right) e^{-kt_{ij}} \qquad \textbf{Eq. (3)}$$

From this equation LandGEM calculates the landfill gas emissions, methane, and other gases, but for the purposes of this study only the landfill gas and methane emissions are taken into account.

The landfill gas and methane production for the biggest landfill, Lomas Los Colorados, shows clearly the peak production year, which is 2026. This is the closure year; the same behavior is present in the other two landfills. This shows that even after the closure year the landfill gas generation is still useful for energetic purposes, may be is not recommendable to install the exact amount of engines to cover the hole gas production because it will decrease after the closure year.

According to the Figure 17 which shows the landfill gas and methane generation there is a useful margin of gas production of approximately 70 years. Figure 18 supports this information showing the electricity generation potential that could be covered in this period of time as the optimal time to use the landfill gas as fuel. Among the main reasons for this is that the fuel will at least constant and even increase within the time.

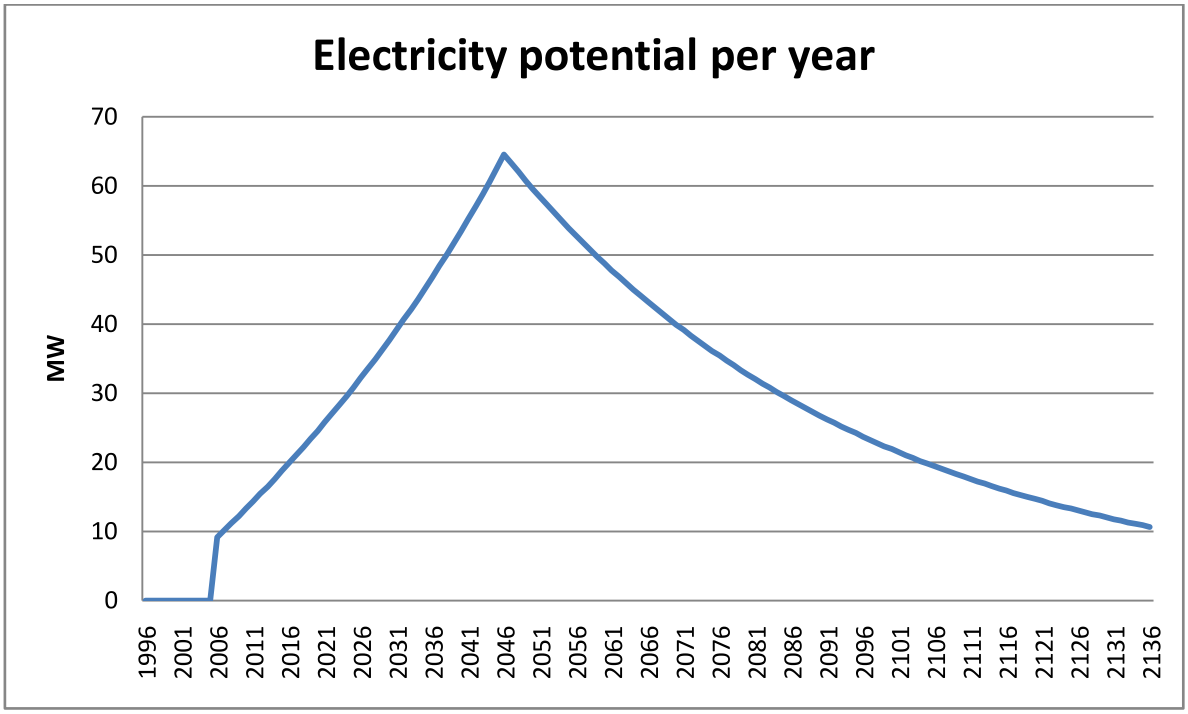
Figure 17. Landfill gas production Lomas Los Colorados



Based on LandGEM (42)

According to the data obtained from the example of this landfill, mentioned within chapter 3, the electricity that could be produced in the landfill, taken into account a collection efficiency of 50%, is illustrated in the next figure. The data contained in the Declaration of Environmental Impact for the "Expansion of the biogas system; capture, thermal degradation and use of energy system, within the framework of the Clean Development Mechanism, in the landfill Lomas Los Colorados" provide the information of the electricity generation system that the landfill was proving. Based on this data it was possible to elaborate the following charts, which represent the potential of electricity generation in each landfill and finally the three of them as a general sum. (59)

Figure 18. Electricity production potential LLC



(Self elaborated, based on Environmental Impact Declaration of LLC, 2006)

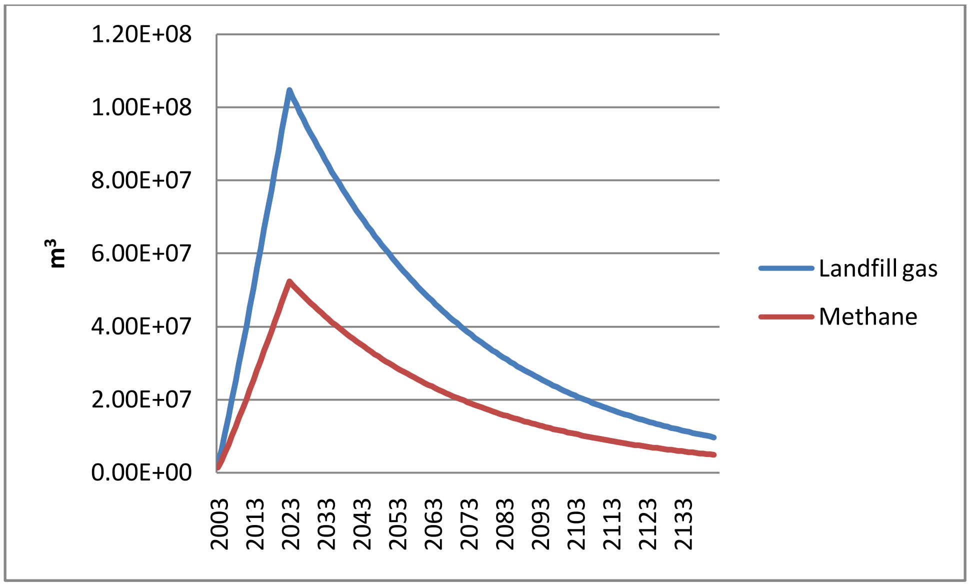
During the first ten years of the landfill it is not advisable to count with an electricity generation system, because installation of the collecting system is still too small in these first years. This means that the pipes are not enough to achieve the 50% of collecting efficiency during this first stage; although there are new wells perforations during the whole operational time of the landfill, the manager tries to keep the efficiency at the adequate level, having enough wells during the operational time.

6.2.2 Santa Marta

For the landfill Santa Marta calculations show a lower landfill gas production level in comparison with Lomas Los Colorados, because of the smaller size of the landfill. It is important to mention that the collection efficiency of the gas is assumed the same for all the landfills due to their participation within the Clean Development Mechanism.

In the particular case of Santa Marta, the production peak is the year 2023, this happens because Santa Marta is smaller and its full capacity will be reached in the next 13 years (See Figure 19). Although its life time is shorter, it is possible to use the biogas also as fuel for many purposes; the electricity generation potential of this landfill was estimated taken the same considerations as in the previous case.

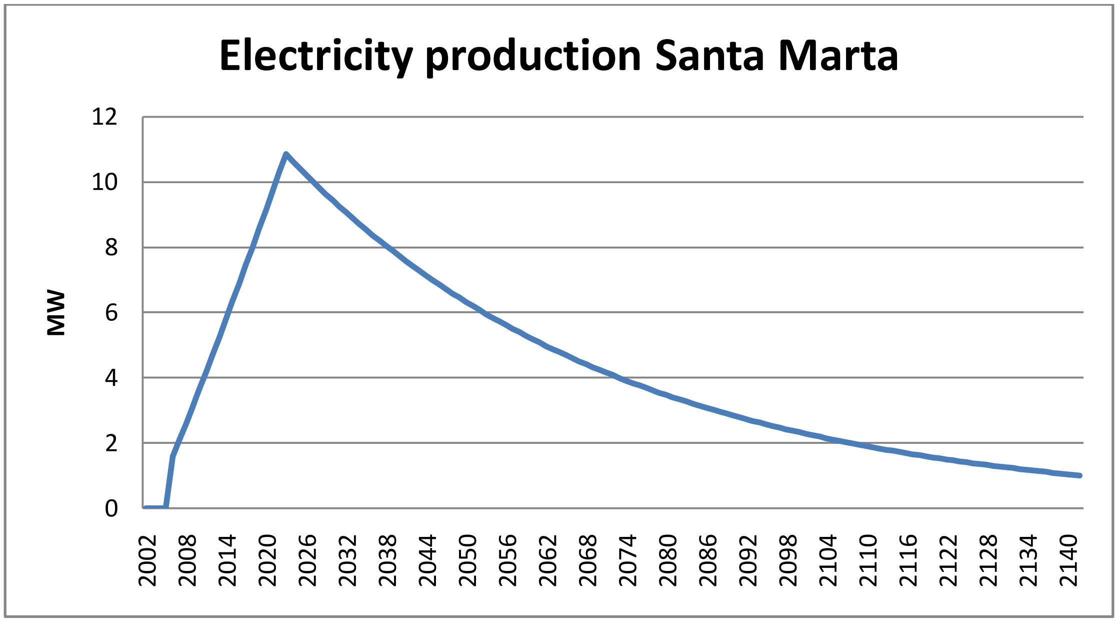
Figure 19. Landfill gas production Santa Marta



Based on LandGEM (42)

According to the information available of Santa Marta, the collection efficiency is already achieved, 50%. Like Lomas Los Colorados the Santa Marta landfill has a registered project on the Clean Development Mechanism for flaring the landfill gas, that is why the time for the calculation was reduced and it is only four years after the opening year. For the potential of electricity production in Santa Marta the calculations showed a margin of 63 years of possible use of the landfill gas, of course the amount of electricity would be minor in comparison to Lomas Los Colorados, but still could be a maximum of approximately 90 GWh in the peak year (See Figure 20), during the 63 years it could be produced at least 30 GWh per year (See Figure 20).

Figure 20. Electricity Production Santa Marta

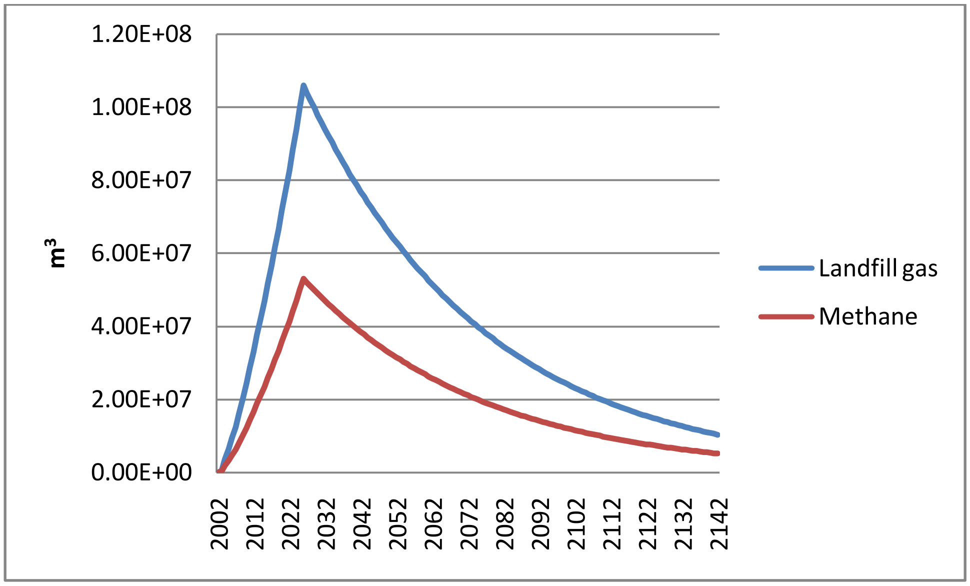


(Elaborated model, based on Environmental Impact Declaration of LLC, 2006)

6.2.3 Santiago Poniente

During the research it was palpable that Santiago Poniente has the least released information of the three landfills and also, the visit to its installations was not possible, mainly due to the lack of contact with the company, which manages the place. Despite these obstacles it was possible to get the waste incomes quantities and to calculate its landfill gas production rates (See Figure 21). It is possible to observe that the amounts of landfill gas emissions are similar to the figures of Santa Marta, this result confirms the similarities of sizes and waste reception between Santa Marta and Santiago Poniente.

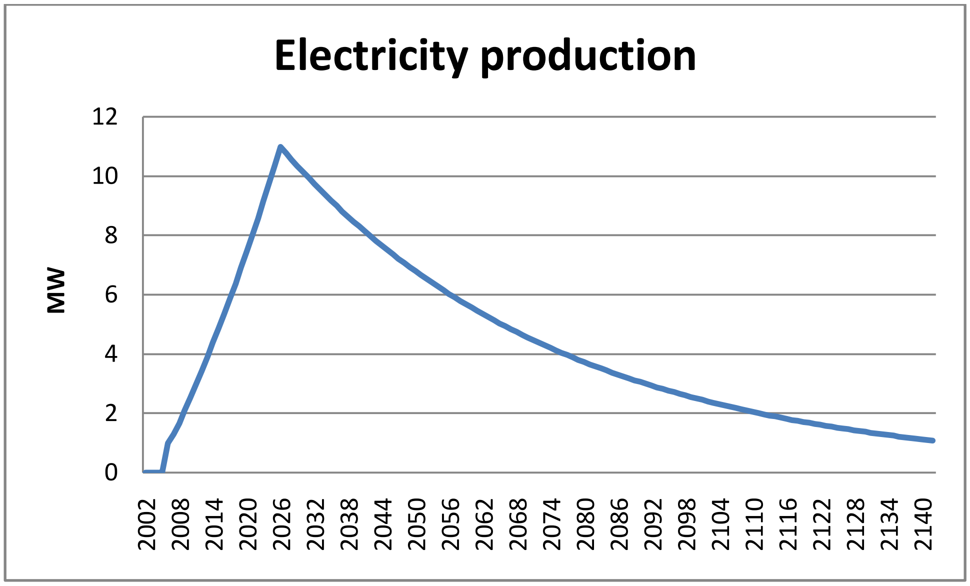
Figure 21. Landfill gas production Santiago Poniente



Based on LandGEM (42)

Assuming a collecting efficiency of 50% of the landfill gas Figure 22 shows the electricity production potential, taking into account the same assumptions as in the last cases, engines of 1 MW which consume 550 m^3/h to generate 1 MWh. Within the period between 2012 and 2079 the landfill Santiago Poniente could produce at least 30 GWh per year, which is a period of time similar to Santa Marta.

Figure 22. Electricity production Santiago Poniente

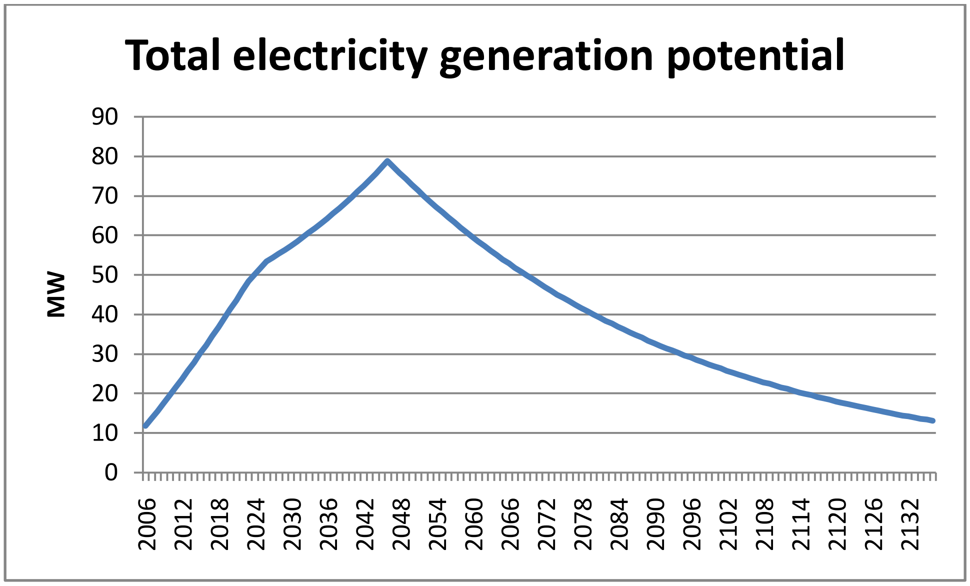


(Elaborated model, based on Environmental Impact Declaration of LLC, 2006)

6.3 Total electricity production potential

Figure 23 shows the total electricity production potential of the three landfills, with the assumptions already mentioned (50% collection efficiency, 1MW engines and a consumption of 550 m^3/h of landfill gas per engine, landfill gas with a 50% methane proportion). According to the calculations, the landfills could provide an important amount of electricity to the Metropolitan Region of Santiago; having enough landfill gas to generate 200 GWh per year at least for approximately 80 years.

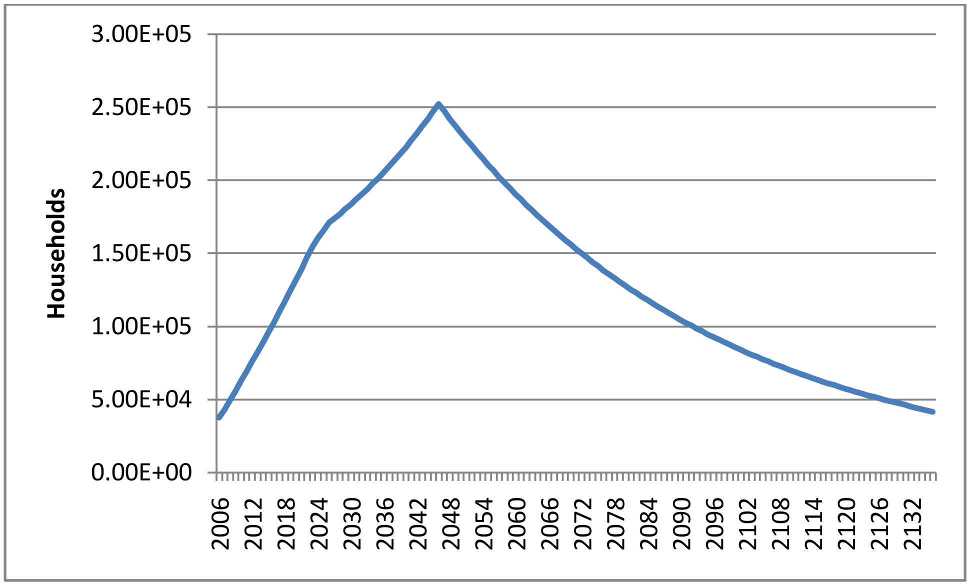
Figure 23. Total electricity generation potential



(Elaborated model, based on Environmental Impact Declaration of LLC, 2006)

Based on a simulation tool provided by Chilectra, which is a Chilean electricity distribution company, a monthly electrical consumption of 213.64 kWh per household was calculated. (60) The theoretical amount of households which could be provided with electricity from the landfills in time (See Figure 24), assuming that all the landfill gas is use to produce electricity, shows the great potential of the landfill gas as a fuel useful for the energetic supply of the actual conditions of the Megacities. For example if the three landfill had enough generator engines installed to use the total amount of landfill gas that they capture, it would be possible to cover the demand of 62,296 households during 2010, assuming a constant consumption rate and the total use of the landfill gas with a capture efficiency of 50%.

Figure 24. Electricity consumption, households.



(Elaborated model, based on Environmental Impact Declaration of LLC, 2006)

7 CONCLUSIONS AND RECOMMENDATIONS

The particular case of the Metropolitan Region of Santiago de Chile shows many positive aspects of an adequate waste management. Two of the three landfills in the Metropolitan Region, Lomas Los Colorados and Santa Marta, seem to accomplish the requirements of the Chilean government as much as environmental and health requirements. In the case of Santiago Poniente, there was a fee registered for the lack of reforestation in the surroundings of the installations. The difficulty of not being able to contact the company in charge of the landfill to visit the installation limits the information of Santiago Poniente.

The CDM also prove to be a useful tool to motivate the private sector to invest in CO_2e emission reduction projects, with the registration of the landfills through projects of landfill gas flaring. Lomas Los Colorados seem to be the only landfill interested in the continuity of the project from flaring gases to generating energy, since they proved the feasibility of the project with two initial engines. Now a days there is a project in registration for the Clean Development Mechanism and also with its Environmental Impact Declaration for the so called “Central Lomas Los Colorados”. This project means for Lomas Los Colorados an expansion from 2 engines to 28 individual generator engines, an electric sub-station of 110kV and its respective transmission line. According to the regulations of the Clean Development Mechanism, the project has to prove its additionality and also that it would be not possible to make without the support of the CERs. That is why the company decided to make a test with two engines and then to go on with a bigger central.

For the case of the Santa Marta landfill, their participation in the Clean Development Mechanism is registered since March of 2007 with a first project of at least 16 years. According to the Project Design Document at the beginning of the project no electricity generation would be planned due to the high investment costs in power generation equipment and grid connection, also because of the low price of electricity and the uncertainty and variation in the production of biogas in that time. They assure that the feasibility of electricity generation should be revisited every three years once the project was fully operational. (61) During the visit to the installation it was possible to check that the landfill gas collecting system and the torches were in good conditions and working, but the only modification that the company attempts to do in the near future for it is to change two of the torches due to law requirements of emissions. As far Santa Marta seem to have an excellent waste management but not much interest in the generation of electricity.

During the fieldwork phase of the investigation and during the constant literature review no information was found about Santiago Poniente that could show that they are registered in the Clean Development Mechanism, but only that they have the necessary installations to burn the 5% of the landfill gas as the regulations require. Santiago Poniente seems to have some problems to cover the environmental regulations and according the available bibliography its energetic potential is not being use.

The Chilean government also offers a solid market to participate in the CERs trade, institutions like ProChile work for the introduction of foreign investments into Chile and CDM projects, at a national level there are also institutions such as the CGF-MDL (Centro de Gestión y Fortalecimiento para el Mejoramiento de desarrollo Limpio en Chile). This institution, in particular, attempts to support the creation of CDM projects through many strategic goals, e.g. management of CDM projects and resources, supporting PYMES (small and medium companies), training of human resources, etc.

Within the framework of the Clean Development Mechanism is important to notice that the size of the project is an important factor to participate of it, to small projects could invest much more in the registration process than the amount that they could get from the CERs emissions, this is why it is more convenient to combine the CDM with another income source. According to ProChile, a project can be competitive within the market with an amount of 50,000 tCO_2e of emissions reductions as a baseline. But since two of the three landfills are already registered in the Clean Development Mechanism, and Lomas Los Colorados is already registering to extend its electricity generation system it is possible to assume that Santa Marta could also try to start an electricity project with the support of the CDM; and since Santiago Poniente theoretically has similar size and gas generation potential as Santa Marta the reasons why it is not trying to enter the mechanism could be more administrative than technical.

Regarding the objectives planned in this investigation it is possible to say that they are not completely fulfilled because the time was too short and the information was not that easily available to collect. For the first two objectives "To review the landfills on the MR of Santiago de Chile and the possible, or actual, biogas generation" and "To describe the procedures for the application of the CDM founds for projects focused in the biogas use" the fieldwork and the literature review were enough in the case of Lomas Los Colorados and Santa Marta, but it was not for the landfill Santiago Poniente, although as an advantage the National Environmental Commission (CONAMA) has a useful register of the amounts of waste that receive each landfill.

For the second part of the objectives "To make a general description of the financial possibilities of the CDM and how could it be adapted to the case of Santiago de Chile" and "To recommend the use alternatives of the biogas in the future of the MR of Santiago de Chile" the main obstacle was the time, because in order to end correctly the possibilities of adaptation of the Clean Development Mechanism in the case of Santiago and its landfills is necessary to know deeply the market and institutional dynamics for the mechanism. About the use alternatives of the biogas in the future the investigation only achieved one of the three possibilities that had taken into account. Electricity generation seem to be the most studied way to use the landfill gas, therefore there was more information in this subject and also more specifically documented. On the contrary the use of landfill gas as substitute of natural gas and for heat uses have less studies and information published.

But as a positive aportation of this study is to answer the hypothesis written at the beginning of the work, and it is possible to say that the introduction of the Clean Development Mechanism is convenient for the use of the landfill gas of the Metropolitan Region of Santiago de Chile due to its potential landfill gas production and its use possibilities. The project also accomplished to be a base to further works, because it has the first steps to go in more detailed projects within the area of landfill gas and Clean Development Mechanism application.

At the beginning of the investigative work, there were many use possibilities taken into account, but due to the lack of specific information it was only possible to calculate the electricity generation of the three landfills, as shown in the Chapter 5.

According to the calculations results, it is possible to appreciate the great potential of the biogas, worldwide the use of landfill gas as fuel is growing. In the case of Santiago de Chile there was a landfill “Lepanto”, which provided gas to a company close to the installations, located approximately 4 km from the landfill, it is important to mention that the treatment of the landfill gas was rather simple compared to the treatment needed to inject the gas directly to the pipelines of the gas net. The use of the gas by the company began mainly after the closure year of the landfill.

It is important that in order to use the landfill gas a SNG there are certain conditions which are necessary, e.g. the distance between the landfill and the connection or end user needs to be short; because the cost of pipelines installation, management, etc., raise the costs of the initial investments discouraging the companies.

As a clear example of this is the landfill, Lomas Los Colorados, which before the begging of its electricity generation project, made studies to evaluate the best use possibility for the gas. The company took into account the use of the gas as SNG, the use for heating and the electricity generation, the final decision was the electricity generation as the most suitable because of the aspects mentioned before.

This happens, above all, due to the national regulations which ask for a minimum distance of the landfills to the next populations or installations. They are required to keep a kind of isolation to avoid the pollution through smells, leachates, or any other factor that could affect the surroundings of the landfill.

The advantage of the electricity generation is that the landfill by itself is connected to the grid, of course it is necessary to make a special installation to be able to produce, transform and put the electricity into the grid, but the problem of connection is minimum compared with the other possibilities.

The potential of landfill gas as a fuel is still underestimated; most of the companies prefer to enter to the CDM only with the flaring of landfill gas than to invest in the electricity generation, at least in the case of two of the three landfills in the MR of Santiago. In order to motivate the further investments the Chilean government is promoting the renewable sources, but they are still at the beginning. It will take time for the companies and government to achieve the optimal conditions, such as more stable prices and a bigger support of the projects.

7.1 Recommendations

To go deeper into the economical aspect of the CDM project costs and the investments for the different use possibilities of the landfill gas, is necessary to obtain more data and to do a more extended study that can help to take a look into the investment and management costs of the projects. Nowadays there are many studies in the area, but mainly with a national scope and mostly theoretical projections.

If more detailed information exists it is not public available, mainly for confidentiality issues of the companies. A further investigation could follow this first work to achieve more specific figures.

An interesting point to take into account is the lack of municipal participation in the waste management in the MR, in which few Comunas take care of its own waste recollection and also the few existence of recycling programs in the MR. It is still necessary to promote these kind of programs to be able to achieve a higher biogas generation efficiency.

The application of European technology, such as the biodigestors, seems to be far from urban solid waste; but rather possible in other areas such as the agriculture or farming; organizations such as GTZ and CNE have an extended study in the potential of these areas.

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9 APPENDIX

9.1 Calculations

9.1.1 Lomas Los Colorados

Table 5. Landfill gas emissions according to Weber and Doedens - Lomas Los Colorados landfill

Year	Waste Accepted (tons)	Landfill gas production (m^3/year)
1996	544,867	3,002,516.08
1997	1,118,610	8,963,682.20
1998	1,284,802	15,437,645.74
1999	1,346,151	21,811,995.98
2000	1,409,470	28,104,323.18
2001	1,534,759	34,661,661.29
2002	1,771,241	42,078,828.37
2003	1,689,504	48,544,133.41
2004	1,730,062	54,795,840.71
2005	1,675,812	60,325,946.69
2006	1,718,210	65,715,819.57
2007	1,761,681	70,980,852.79
2008	1,806,251	76,135,542.38
2009	1,851,949	81,193,564.15
2010	1,898,804	86,167,829.14
2011	1,946,843	91,070,524.32
2012	1,996,099	95,913,194.58
2013	2,046,600	100,706,758.63
2014	2,098,379	105,461,578.81
2015	2,151,468	110,187,493.28
2016	2,205,900	114,893,856.91
2017	2,261,709	119,589,579.47
2018	2,318,931	124,283,166.78
2019	2,377,599	128,982,731.45
2020	2,437,753	133,696,058.04
2021	2,499,428	138,430,597.71
2022	2,562,663	143,193,512.78
2023	2,627,499	148,358,026.51
2024	2,693,975	153,173,387.20

(Source: elaborated model)

Table 5. Landfill gas emissions according to Weber and Doedens - Lomas Los Colorados landfill (Continued)

Year	Waste acepted (tons)	Landfill gas production (m³/year)
2025	2,762,132	158,038,782.20
2026	2,832,014	162,960,334.59
2027	2,903,664	151,943,208.86
2028	2,977,127	141,670,908.92
2029	0	132,093,079.94
2030	0	123,162,771.39
2031	0	114,836,206.88
2032	0	107,072,569.60
2033	0	99,833,802.18
2034	0	93,084,420.17
2035	0	86,791,338.09
2036	0	80,923,707.26
2037	0	75,452,764.53
2038	0	70,351,691.35
2039	0	65,595,482.23
2040	0	61,160,822.25
2041	0	57,025,972.68
2042	0	53,170,664.50
2043	0	49,575,998.98
2044	0	46,224,355.07
2045	0	43,099,302.99
2046	0	40,185,523.75
2047	0	37,468,734.00
2048	0	34,935,616.02
2049	0	32,573,752.47
2050	0	30,371,565.49
2051	0	28,318,259.97
2052	0	26,403,770.58
2053	0	24,618,712.52
2054	0	22,954,335.40
2055	0	21,402,480.47
2056	0	19,955,540.52
2057	0	18,606,422.65

(Source: elaborated model)

Table 5. Landfill gas emissions according to Weber and Doedens - Lomas Los Colorados landfill (Continued)

Year	Waste acepted (tons)	Landfill gas production (m^3/year)
2058	0	17,348,513.49
2059	0	16,175,646.77
2060	0	15,082,073.08
2061	0	14,062,431.73
2062	0	13,111,724.44
2063	0	12,225,290.83
2064	0	11,398,785.62
2065	0	10,628,157.27
2066	0	9,909,628.15
2067	0	9,239,676.05
2068	0	8,615,016.84
2069	0	8,032,588.46
2070	0	7,489,535.84
2071	0	6,983,196.93
2072	0	6,511,089.66
2073	0	6,070,899.76
2074	0	5,660,469.42
2075	0	5,277,786.70
2076	0	4,920,975.71

(Source: elaborated model)

Table 6. Methane emissions avoided according CDM methodological tool - Lomas Los Colorados

Year	Waste acepted (tons)	Methane emission avoided (tCO_2e)
1996	544,867	26897.4099
1997	1,118,610	79503.9777
1998	1,284,802	135202.6591
1999	1,346,151	188517.3978
2000	1,409,470	239777.0992
2001	1,534,759	292240.6137
2002	1,771,241	351280.0150
2003	1,689,504	400547.3902
2004	1,730,062	447029.4263
2005	1,675,812	486316.5789
2006	1,718,210	523879.0385
2007	1,761,681	559937.3682
2008	1,806,251	594691.9822
2009	1,851,949	628325.2510
2010	1,898,804	661003.2551
2011	1,946,843	692877.2694
2012	1,996,099	724085.4978
2013	2,046,600	754754.0965
2014	2,098,379	784998.5920
2015	2,151,468	814924.8642
2016	2,205,900	844630.1333
2017	2,261,709	874203.8508
2018	2,318,931	903728.5527
2019	2,377,599	933280.3841
2020	2,437,753	962930.0652
2021	2,499,428	992743.1719
2022	2,562,663	1022780.8332
2023	2,627,499	1053100.2617
2024	2,693,975	1083755.0358
2025	2,762,132	1114795.5516
2026	2,832,014	1146269.4799
2027	2,903,664	1178221.9820
2028	2,977,127	1210696.0519

(Source: elaborated model)

Table 6. Methane emissions avoided according CDM methodological tool - Lomas Los Colorados (Continued)

Year	Waste acepted (tons)	Methane emission avoided (tCO_2e)
2029	3,052,448	1243732.7275
2030	3,129,675	1277371.4282
2031	3,208,856	1311650.1123
2032	3,290,040	1346605.4688
2033	3,373,278	1382273.1387
2034	3,458,622	1418687.8670
2035	3,546,125	1455883.6385
2036	3,635,842	1493893.8506
2037	3,727,829	1532751.4202
2038	3,822,143	1572488.8789
2039	3,918,843	1613138.5098
2040	4,017,990	1654732.4703
2041	4,119,645	1697302.8041
2042	4,223,872	1740881.6005
2043	4,330,736	1785501.0393
2044	4,440,303	1831193.4314
2045	4,552,643	1877991.4035
2046	0	1695500.2047
2047	0	1530742.3339
2048	0	1381994.5797
2049	0	1247701.1814
2050	0	1126457.5570
2051	0	1016995.6129
2052	0	918170.4808
2053	0	828948.5432
2054	0	748396.6231
2055	0	675672.2237
2056	0	610014.7165
2057	0	550737.3861
2058	0	497220.2477
2059	0	448903.5627
2060	0	405281.9843
2061	0	365899.2720
2062	0	330343.5199

(Source: elaborated model)

Table 6. Methane emissions avoided according CDM methodological tool - Lomas Los Colorados (Continued)

Year	Waste acepted (tons)	Methane emission avoided (tCO_2e)
2063	0	298242.8484
2064	0	269261.5151
2065	0	243096.4024
2066	0	219473.8481
2067	0	198146.7826
2068	0	178892.1450
2069	0	161508.5500
2070	0	145814.1816
2071	0	131644.8916
2072	0	118852.4826
2073	0	107303.1582
2074	0	96876.1232
2075	0	87462.3209

(Source: elaborated model)

Table 7. Landfill gas and methane emissions according to LandGEM v. 3.02 - Lomas Los Colorados

Year	Waste Accepted	Waste-In-Place	Total landfill gas		Methane	
	(Mg/year)	(Mg)	(Mg/year)	(m^3/year)	(Mg/year)	(m^3/year)
1996	544,867	0	0	0	0	0
1997	1,118,610	544,867	4.586E+03	3.672E+06	1.225E+03	1.836E+06
1998	1,284,802	1,663,477	1.391E+04	1.114E+07	3.715E+03	5.569E+06
1999	1,346,151	2,948,279	2.445E+04	1.958E+07	6.530E+03	9.788E+06
2000	1,409,470	4,294,430	3.529E+04	2.826E+07	9.427E+03	1.413E+07
2001	1,534,759	5,703,900	4.646E+04	3.720E+07	1.241E+04	1.860E+07
2002	1,771,241	7,238,659	5.845E+04	4.681E+07	1.561E+04	2.340E+07
2003	1,689,504	9,009,900	7.220E+04	5.782E+07	1.929E+04	2.891E+07
2004	1,730,062	10,699,404	8.499E+04	6.806E+07	2.270E+04	3.403E+07
2005	1,675,812	12,429,466	9.787E+04	7.837E+07	2.614E+04	3.918E+07
2006	1,718,210	14,105,278	1.100E+05	8.811E+07	2.939E+04	4.405E+07
2007	1,761,681	15,823,488	1.223E+05	9.794E+07	3.267E+04	4.897E+07
2008	1,806,251	17,585,169	1.347E+05	1.079E+08	3.599E+04	5.394E+07
2009	1,851,949	19,391,420	1.473E+05	1.179E+08	3.933E+04	5.896E+07
2010	1,898,804	21,243,369	1.599E+05	1.281E+08	4.272E+04	6.403E+07
2011	1,946,843	23,142,173	1.727E+05	1.383E+08	4.614E+04	6.916E+07
2012	1,996,099	25,089,016	1.857E+05	1.487E+08	4.960E+04	7.435E+07
2013	2,046,600	27,085,115	1.988E+05	1.592E+08	5.311E+04	7.960E+07
2014	2,098,379	29,131,715	2.121E+05	1.698E+08	5.666E+04	8.492E+07
2015	2,151,468	31,230,094	2.256E+05	1.806E+08	6.025E+04	9.031E+07
2016	2,205,900	33,381,562	2.392E+05	1.915E+08	6.390E+04	9.577E+07
2017	2,261,709	35,587,462	2.530E+05	2.026E+08	6.759E+04	1.013E+08
2018	2,318,931	37,849,171	2.671E+05	2.139E+08	7.134E+04	1.069E+08
2019	2,377,599	40,168,102	2.813E+05	2.252E+08	7.514E+04	1.126E+08
2020	2,437,753	42,545,701	2.957E+05	2.368E+08	7.899E+04	1.184E+08
2021	2,499,428	44,983,454	3.104E+05	2.485E+08	8.291E+04	1.243E+08
2022	2,562,663	47,482,882	3.253E+05	2.605E+08	8.689E+04	1.302E+08
2023	2,627,499	50,045,545	3.404E+05	2.726E+08	9.093E+04	1.363E+08
2024	2,693,975	52,673,044	3.558E+05	2.849E+08	9.503E+04	1.424E+08
2025	2,762,132	55,367,019	3.714E+05	2.974E+08	9.921E+04	1.487E+08
2026	2,832,014	58,129,151	3.873E+05	3.101E+08	1.035E+05	1.551E+08
2027	2,903,664	60,961,165	4.035E+05	3.231E+08	1.078E+05	1.615E+08
2028	2,977,127	63,864,829	4.199E+05	3.362E+08	1.122E+05	1.681E+08
2029	3,052,448	66,841,956	4.367E+05	3.497E+08	1.166E+05	1.748E+08
2030	3,129,675	69,894,404	4.537E+05	3.633E+08	1.212E+05	1.817E+08
2031	3,208,856	73,024,079	4.711E+05	3.772E+08	1.258E+05	1.886E+08

(Source: LandGEM v. 3.02, 2005)

Table 7. Landfill gas and methane emissions according to LandGEM v. 3.02 - Lomas Los Colorados (Continued)

Year	Waste Accepted	Waste-In-Place	Total landfill gas		Methane	
	(Mg/year)	*(Mg)*	*(Mg/year)*	*(m^3/year)*	*(Mg/year)*	*(m^3/year)*
2033	3,373,278	79,522,975	5.067E+05	4.058E+08	1.354E+05	2.029E+08
2034	3,458,622	82,896,253	5.251E+05	4.205E+08	1.403E+05	2.102E+08
2035	3,546,125	86,354,875	5.438E+05	4.355E+08	1.453E+05	2.177E+08
2036	0	86,354,875	5.629E+05	4.507E+08	1.504E+05	2.254E+08
2037	0	86,354,875	5.823E+05	4.663E+08	1.555E+05	2.332E+08
2038	0	86,354,875	6.022E+05	4.822E+08	1.608E+05	2.411E+08
2039	0	86,354,875	6.224E+05	4.984E+08	1.663E+05	2.492E+08
2040	0	86,354,875	6.431E+05	5.149E+08	1.718E+05	2.575E+08
2041	0	86,354,875	6.642E+05	5.318E+08	1.774E+05	2.659E+08
2042	0	86,354,875	6.857E+05	5.491E+08	1.832E+05	2.745E+08
2043	0	86,354,875	7.077E+05	5.667E+08	1.890E+05	2.833E+08
2044	0	86,354,875	7.301E+05	5.846E+08	1.950E+05	2.923E+08
2045	0	86,354,875	7.530E+05	6.030E+08	2.011E+05	3.015E+08
2046	0	86,354,875	7.764E+05	6.217E+08	2.074E+05	3.109E+08
2047	0	86,354,875	7.610E+05	6.094E+08	2.033E+05	3.047E+08
2048	0	86,354,875	7.460E+05	5.973E+08	1.993E+05	2.987E+08
2049	0	86,354,875	7.312E+05	5.855E+08	1.953E+05	2.928E+08
2050	0	86,354,875	7.167E+05	5.739E+08	1.914E+05	2.870E+08
2051	0	86,354,875	7.025E+05	5.625E+08	1.877E+05	2.813E+08
2052	0	86,354,875	6.886E+05	5.514E+08	1.839E+05	2.757E+08
2053	0	86,354,875	6.750E+05	5.405E+08	1.803E+05	2.702E+08
2054	0	86,354,875	6.616E+05	5.298E+08	1.767E+05	2.649E+08
2055	0	86,354,875	6.485E+05	5.193E+08	1.732E+05	2.596E+08
2056	0	86,354,875	6.357E+05	5.090E+08	1.698E+05	2.545E+08
2057	0	86,354,875	6.231E+05	4.989E+08	1.664E+05	2.495E+08
2058	0	86,354,875	6.107E+05	4.891E+08	1.631E+05	2.445E+08
2059	0	86,354,875	5.987E+05	4.794E+08	1.599E+05	2.397E+08
2060	0	86,354,875	5.868E+05	4.699E+08	1.567E+05	2.349E+08
2061	0	86,354,875	5.752E+05	4.606E+08	1.536E+05	2.303E+08
2062	0	86,354,875	5.638E+05	4.515E+08	1.506E+05	2.257E+08
2063	0	86,354,875	5.526E+05	4.425E+08	1.476E+05	2.213E+08
2064	0	86,354,875	5.417E+05	4.338E+08	1.447E+05	2.169E+08
2065	0	86,354,875	5.310E+05	4.252E+08	1.418E+05	2.126E+08
2066	0	86,354,875	5.204E+05	4.167E+08	1.390E+05	2.084E+08
2067	0	86,354,875	5.101E+05	4.085E+08	1.363E+05	2.042E+08
2068	0	86,354,875	5.000E+05	4.004E+08	1.336E+05	2.002E+08

(Source: LandGEM v. 3.02, 2005)

Table 7. Landfill gas and methane emissions according to LandGEM v. 3.02 - Lomas Los Colorados (Continued)

Year	Waste Accepted	Waste-In-Place	Total landfill gas		Methane	
	(Mg/year)	*(Mg)*	*(Mg/year)*	*(m^3/year)*	*(Mg/year)*	*(m^3/year)*
2069	0	86,354,875	4.901E+05	3.925E+08	1.309E+05	1.962E+08
2070	0	86,354,875	4.804E+05	3.847E+08	1.283E+05	1.924E+08
2071	0	86,354,875	4.709E+05	3.771E+08	1.258E+05	1.885E+08
2072	0	86,354,875	4.616E+05	3.696E+08	1.233E+05	1.848E+08
2073	0	86,354,875	4.524E+05	3.623E+08	1.209E+05	1.812E+08
2074	0	86,354,875	4.435E+05	3.551E+08	1.185E+05	1.776E+08
2075	0	86,354,875	4.347E+05	3.481E+08	1.161E+05	1.740E+08
2076	0	86,354,875	4.261E+05	3.412E+08	1.138E+05	1.706E+08
2077	0	86,354,875	4.177E+05	3.344E+08	1.116E+05	1.672E+08
2078	0	86,354,875	4.094E+05	3.278E+08	1.094E+05	1.639E+08
2079	0	86,354,875	4.013E+05	3.213E+08	1.072E+05	1.607E+08
2080	0	86,354,875	3.933E+05	3.150E+08	1.051E+05	1.575E+08
2081	0	86,354,875	3.856E+05	3.087E+08	1.030E+05	1.544E+08
2082	0	86,354,875	3.779E+05	3.026E+08	1.009E+05	1.513E+08
2083	0	86,354,875	3.704E+05	2.966E+08	9.895E+04	1.483E+08
2084	0	86,354,875	3.631E+05	2.908E+08	9.699E+04	1.454E+08
2085	0	86,354,875	3.559E+05	2.850E+08	9.507E+04	1.425E+08
2086	0	86,354,875	3.489E+05	2.794E+08	9.318E+04	1.397E+08
2087	0	86,354,875	3.420E+05	2.738E+08	9.134E+04	1.369E+08
2088	0	86,354,875	3.352E+05	2.684E+08	8.953E+04	1.342E+08
2089	0	86,354,875	3.285E+05	2.631E+08	8.776E+04	1.315E+08
2090	0	86,354,875	3.220E+05	2.579E+08	8.602E+04	1.289E+08
2091	0	86,354,875	3.157E+05	2.528E+08	8.432E+04	1.264E+08
2092	0	86,354,875	3.094E+05	2.478E+08	8.265E+04	1.239E+08
2093	0	86,354,875	3.033E+05	2.429E+08	8.101E+04	1.214E+08
2094	0	86,354,875	2.973E+05	2.380E+08	7.941E+04	1.190E+08
2095	0	86,354,875	2.914E+05	2.333E+08	7.783E+04	1.167E+08
2096	0	86,354,875	2.856E+05	2.287E+08	7.629E+04	1.144E+08
2097	0	86,354,875	2.800E+05	2.242E+08	7.478E+04	1.121E+08
2098	0	86,354,875	2.744E+05	2.197E+08	7.330E+04	1.099E+08
2099	0	86,354,875	2.690E+05	2.154E+08	7.185E+04	1.077E+08
2100	0	86,354,875	2.637E+05	2.111E+08	7.043E+04	1.056E+08
2101	0	86,354,875	2.584E+05	2.069E+08	6.903E+04	1.035E+08
2102	0	86,354,875	2.533E+05	2.029E+08	6.767E+04	1.014E+08
2103	0	86,354,875	2.483E+05	1.988E+08	6.633E+04	9.942E+07

(Source: LandGEM v. 3.02, 2005)

Table 7. Landfill gas and methane emissions according to LandGEM v. 3.02 - Lomas Los Colorados (Continued)

Year	Waste Accepted	Waste-In-Place	Total landfill gas		Methane	
	(Mg/year)	(Mg)	(Mg/year)	(m^3/year)	(Mg/year)	(m^3/year)
2104	0	86,354,875	2.434E+05	1.949E+08	6.501E+04	9.745E+07
2105	0	86,354,875	2.386E+05	1.910E+08	6.373E+04	9.552E+07
2106	0	86,354,875	2.338E+05	1.873E+08	6.246E+04	9.363E+07
2107	0	86,354,875	2.292E+05	1.835E+08	6.123E+04	9.177E+07
2108	0	86,354,875	2.247E+05	1.799E+08	6.001E+04	8.996E+07
2109	0	86,354,875	2.202E+05	1.764E+08	5.883E+04	8.818E+07
2110	0	86,354,875	2.159E+05	1.729E+08	5.766E+04	8.643E+07
2111	0	86,354,875	2.116E+05	1.694E+08	5.652E+04	8.472E+07
2112	0	86,354,875	2.074E+05	1.661E+08	5.540E+04	8.304E+07
2113	0	86,354,875	2.033E+05	1.628E+08	5.430E+04	8.140E+07
2114	0	86,354,875	1.993E+05	1.596E+08	5.323E+04	7.978E+07
2115	0	86,354,875	1.953E+05	1.564E+08	5.217E+04	7.820E+07
2116	0	86,354,875	1.915E+05	1.533E+08	5.114E+04	7.666E+07
2117	0	86,354,875	1.877E+05	1.503E+08	5.013E+04	7.514E+07
2118	0	86,354,875	1.840E+05	1.473E+08	4.914E+04	7.365E+07
2119	0	86,354,875	1.803E+05	1.444E+08	4.816E+04	7.219E+07
2120	0	86,354,875	1.767E+05	1.415E+08	4.721E+04	7.076E+07
2121	0	86,354,875	1.732E+05	1.387E+08	4.627E+04	6.936E+07
2122	0	86,354,875	1.698E+05	1.360E+08	4.536E+04	6.799E+07
2123	0	86,354,875	1.664E+05	1.333E+08	4.446E+04	6.664E+07
2124	0	86,354,875	1.632E+05	1.306E+08	4.358E+04	6.532E+07
2125	0	86,354,875	1.599E+05	1.281E+08	4.272E+04	6.403E+07
2126	0	86,354,875	1.568E+05	1.255E+08	4.187E+04	6.276E+07
2127	0	86,354,875	1.536E+05	1.230E+08	4.104E+04	6.152E+07
2128	0	86,354,875	1.506E+05	1.206E+08	4.023E+04	6.030E+07
2129	0	86,354,875	1.476E+05	1.182E+08	3.943E+04	5.911E+07
2130	0	86,354,875	1.447E+05	1.159E+08	3.865E+04	5.794E+07
2131	0	86,354,875	1.418E+05	1.136E+08	3.789E+04	5.679E+07
2132	0	86,354,875	1.390E+05	1.113E+08	3.714E+04	5.566E+07
2133	0	86,354,875	1.363E+05	1.091E+08	3.640E+04	5.456E+07
2134	0	86,354,875	1.336E+05	1.070E+08	3.568E+04	5.348E+07
2135	0	86,354,875	1.309E+05	1.048E+08	3.497E+04	5.242E+07
2136	0	86,354,875	1.283E+05	1.028E+08	3.428E+04	5.138E+07

(Source: LandGEM v. 3.02, 2005)

9.1.2 Santa Marta

Table 8. Landfill gas emissions according to Weber and Doedens - Santa Marta landfill

Year	Waste acepted (tons)	Landfill gas production (m^3/year)
2002	387,193	2,133,645.84
2003	561,405	5,083,047.73
2004	661,451	8,384,360.17
2005	722,808	11,800,594.21
2006	751,720	15,145,190.70
2007	781,789	18,429,368.48
2008	813,060	21,663,835.92
2009	837,452	24,814,046.67
2010	862,576	27,889,730.72
2011	888,453	30,900,075.99
2012	915,106	33,853,775.97
2013	933,409	36,708,647.15
2014	952,077	39,473,382.31
2015	971,118	42,156,130.64
2016	990,541	44,764,540.00
2017	1,010,351	47,305,768.72
2018	1,030,559	49,786,551.85
2019	1,051,170	52,213,196.63
2020	1,072,193	54,591,633.48
2021	1,093,637	56,927,441.50
2022	1,115,510	59,225,866.70
2023	0	55,221,832.09
2024	0	51,488,494.97
2025	0	48,007,554.50
2026	0	44,761,947.13
2027	0	41,735,762.87
2028	0	38,914,167.37
2029	0	36,283,329.16
2030	0	33,830,351.87
2031	0	31,543,211.01
2032	0	29,410,695.01
2033	0	27,422,350.27
2034	0	25,568,429.91
2035	0	23,839,846.04

(Source: elaborated model)

Table 8. Landfill gas emissions according to Weber and Doedens - Santa Marta landfill (Continued)

Year	Waste acepted (tons)	Landfill gas production (m^3/year)
2036	0	22,228,125.11
2037	0	20,725,366.48
2038	0	19,324,203.62
2039	0	18,017,768.03
2040	0	16,799,655.56
2041	0	15,663,895.02
2042	0	14,604,918.92
2043	0	13,617,536.14
2044	0	12,696,906.54
2045	0	11,838,517.19
2046	0	11,038,160.26
2047	0	10,291,912.41
2048	0	9,596,115.53
2049	0	8,947,358.81
2050	0	8,342,462.06
2051	0	7,778,460.07
2052	0	7,252,588.10
2053	0	6,762,268.32
2054	0	6,305,097.19
2055	0	5,878,833.65
2056	0	5,481,388.17
2057	0	5,110,812.45
2058	0	4,765,289.94
2059	0	4,443,126.89
2060	0	4,142,744.06
2061	0	3,862,668.96
2062	0	3,601,528.66
2063	0	3,358,043.07
2064	0	3,131,018.60
2065	0	2,919,342.40
2066	0	2,721,976.81
2067	0	2,537,954.35
2068	0	2,366,372.95
2069	0	2,206,391.52
2070	0	2,057,225.82
2071	0	1,918,144.64

(Source: elaborated model)

Table 8. Landfill gas emissions according to Weber and Doedens - Santa Marta landfill (Continued)

Year	Waste acepted (tons)	Landfill gas production (m^3/year)
2072	0	1,788,466.21
2073	0	1,667,554.84
2074	0	1,554,817.82
2075	0	1,449,702.53
2076	0	1,351,693.68
2077	0	1,260,310.83
2078	0	1,175,106.03
2079	0	1,095,661.60
2080	0	1,021,588.11
2081	0	952,522.44
2082	0	888,126.03

(Source: elaborated model)

Table 9. Methane emissions avoided according CDM methodological tool - Santa Marta

Year	Waste acepted (tons)	Methane emission avoided (tCO_2e)
2002	387,193	19113.8183
2003	561,405	44970.2694
2004	661,451	73252.9360
2005	722,808	101816.1678
2006	751,720	129031.0509
2007	781,789	155085.7246
2008	813,060	180152.2675
2009	837,452	203987.1173
2010	862,576	226746.0974
2011	888,453	248570.9258
2012	915,106	269590.6847
2013	933,409	289471.4071
2014	952,077	308341.7956
2015	971,118	326318.4410
2016	990,541	343507.0492
2017	1,010,351	360003.3008
2018	1,030,559	375894.1219
2019	1,051,170	391258.2385
2020	1,072,193	406167.1709
2021	1,093,637	420685.9335
2022	1,115,510	434873.6183
2023	0	392615.3802
2024	0	354463.5275
2025	0	320019.0279
2026	0	288921.6246
2027	0	260846.0682
2028	0	235498.7148
2029	0	212614.4552
2030	0	191953.9417
2031	0	173301.0848
2032	0	156460.7933
2033	0	141256.9336
2034	0	127530.4878
2035	0	115137.8903
2036	0	103949.5262
2037	0	93848.3758
2038	0	84728.7906

(Source: elaborated model)

Table 9. Methane emissions avoided according CDM methodological tool - Santa Marta (Continued)

Year	Waste acepted (tons)	Methane emission avoided (tCO_2e)
2039	0	76495.3884
2040	0	69062.0556
2041	0	62351.0465
2042	0	56292.1704
2043	0	50822.0572
2044	0	45883.4945
2045	0	41424.8299
2046	0	37399.4297
2047	0	33765.1922
2048	0	30484.1067
2049	0	27521.8561
2050	0	24847.4581
2051	0	22432.9409
2052	0	20253.0511
2053	0	18284.9891
2054	0	16508.1708
2055	0	14904.0123
2056	0	13455.7356
2057	0	12148.1933
2058	0	10967.7095
2059	0	9901.9376
2060	0	8939.7306
2061	0	8071.0247
2062	0	7286.7342
2063	0	6578.6559
2064	0	5939.3842
2065	0	5362.2328
2066	0	4841.1653
2067	0	4370.7318
2068	0	3946.0120
2069	0	3562.5638
2070	0	3216.3766
2071	0	2903.8297
2072	0	2621.6541
2073	0	2366.8985
2074	0	2136.8985

(Source: elaborated model)

Table 9. Methane emissions avoided according CDM methodological tool - Santa Marta (Continued)

Year	Waste acepted (tons)	Methane emission avoided (tCO_2e)
2075	0	1929.2483
2076	0	1741.7763
2077	0	1572.5216
2078	0	1419.7140
2079	0	1281.7553
2080	0	1157.2025
2081	0	1044.7530

(Source: elaborated model)

Table 10. Landfill gas and methane emissions according to LandGEM v. 3.02 – Santa Marta

Year	Waste Accepted	Waste-In-Place	Total landfill gas		Methane	
	(Mg/year)	*(Mg)*	*(Mg/year)*	*(m^3/year)*	*(Mg/year)*	*(m^3/year)*
2002	387,193	0	0	0	0	0
2003	561,405	387,193	3.259E+03	2.609E+06	8.704E+02	1.305E+06
2004	661,451	948,598	7.919E+03	6.341E+06	2.115E+03	3.171E+06
2005	722,808	1,610,049	1.333E+04	1.067E+07	3.560E+03	5.337E+06
2006	751,720	2,332,857	1.915E+04	1.533E+07	5.115E+03	7.666E+06
2007	781,789	3,084,577	2.510E+04	2.010E+07	6.703E+03	1.005E+07
2008	813,060	3,866,366	3.118E+04	2.497E+07	8.328E+03	1.248E+07
2009	837,452	4,679,426	3.740E+04	2.995E+07	9.991E+03	1.498E+07
2010	862,576	5,516,878	4.371E+04	3.500E+07	1.168E+04	1.750E+07
2011	888,453	6,379,454	5.010E+04	4.012E+07	1.338E+04	2.006E+07
2012	915,106	7,267,907	5.659E+04	4.531E+07	1.512E+04	2.266E+07
2013	933,409	8,183,013	6.317E+04	5.058E+07	1.687E+04	2.529E+07
2014	952,077	9,116,422	6.978E+04	5.587E+07	1.864E+04	2.794E+07
2015	971,118	10,068,499	7.641E+04	6.118E+07	2.041E+04	3.059E+07
2016	990,541	11,039,617	8.307E+04	6.652E+07	2.219E+04	3.326E+07
2017	1,010,351	12,030,158	8.976E+04	7.187E+07	2.398E+04	3.594E+07
2018	1,030,559	13,040,509	9.648E+04	7.726E+07	2.577E+04	3.863E+07
2019	1,051,170	14,071,068	1.032E+05	8.268E+07	2.758E+04	4.134E+07
2020	1,072,193	15,122,238	1.100E+05	8.812E+07	2.940E+04	4.406E+07
2021	1,093,637	16,194,431	1.169E+05	9.360E+07	3.122E+04	4.680E+07
2022	1,115,510	17,288,068	1.238E+05	9.912E+07	3.306E+04	4.956E+07
2023	0	18,403,578	1.307E+05	1.047E+08	3.492E+04	5.234E+07
2024	0	18,403,578	1.281E+05	1.026E+08	3.423E+04	5.130E+07
2025	0	18,403,578	1.256E+05	1.006E+08	3.355E+04	5.029E+07
2026	0	18,403,578	1.231E+05	9.858E+07	3.288E+04	4.929E+07
2027	0	18,403,578	1.207E+05	9.663E+07	3.223E+04	4.831E+07
2028	0	18,403,578	1.183E+05	9.471E+07	3.159E+04	4.736E+07
2029	0	18,403,578	1.159E+05	9.284E+07	3.097E+04	4.642E+07
2030	0	18,403,578	1.136E+05	9.100E+07	3.036E+04	4.550E+07
2031	0	18,403,578	1.114E+05	8.920E+07	2.975E+04	4.460E+07
2032	0	18,403,578	1.092E+05	8.743E+07	2.916E+04	4.372E+07
2033	0	18,403,578	1.070E+05	8.570E+07	2.859E+04	4.285E+07
2034	0	18,403,578	1.049E+05	8.400E+07	2.802E+04	4.200E+07
2035	0	18,403,578	1.028E+05	8.234E+07	2.747E+04	4.117E+07
2036	0	18,403,578	1.008E+05	8.071E+07	2.692E+04	4.035E+07
2037	0	18,403,578	9.880E+04	7.911E+07	2.639E+04	3.956E+07

(Source: LandGEM v. 3.02, 2005)

Table 10. Landfill gas and methane emissions according to LandGEM v. 3.02 – Santa Marta (Continued)

Year	Waste Accepted	Waste-In-Place	Total landfill gas		Methane	
	(Mg/year)	*(Mg)*	*(Mg/year)*	*(m^3/year)*	*(Mg/year)*	*(m^3/year)*
2038	0	18,403,578	9.684E+04	7.755E+07	2.587E+04	3.877E+07
2039	0	18,403,578	9.492E+04	7.601E+07	2.535E+04	3.800E+07
2040	0	18,403,578	9.304E+04	7.450E+07	2.485E+04	3.725E+07
2041	0	18,403,578	9.120E+04	7.303E+07	2.436E+04	3.651E+07
2042	0	18,403,578	8.939E+04	7.158E+07	2.388E+04	3.579E+07
2043	0	18,403,578	8.762E+04	7.017E+07	2.341E+04	3.508E+07
2044	0	18,403,578	8.589E+04	6.878E+07	2.294E+04	3.439E+07
2045	0	18,403,578	8.419E+04	6.741E+07	2.249E+04	3.371E+07
2046	0	18,403,578	8.252E+04	6.608E+07	2.204E+04	3.304E+07
2047	0	18,403,578	8.089E+04	6.477E+07	2.161E+04	3.239E+07
2048	0	18,403,578	7.929E+04	6.349E+07	2.118E+04	3.174E+07
2049	0	18,403,578	7.772E+04	6.223E+07	2.076E+04	3.112E+07
2050	0	18,403,578	7.618E+04	6.100E+07	2.035E+04	3.050E+07
2051	0	18,403,578	7.467E+04	5.979E+07	1.994E+04	2.990E+07
2052	0	18,403,578	7.319E+04	5.861E+07	1.955E+04	2.930E+07
2053	0	18,403,578	7.174E+04	5.745E+07	1.916E+04	2.872E+07
2054	0	18,403,578	7.032E+04	5.631E+07	1.878E+04	2.815E+07
2055	0	18,403,578	6.893E+04	5.519E+07	1.841E+04	2.760E+07
2056	0	18,403,578	6.756E+04	5.410E+07	1.805E+04	2.705E+07
2057	0	18,403,578	6.623E+04	5.303E+07	1.769E+04	2.652E+07
2058	0	18,403,578	6.491E+04	5.198E+07	1.734E+04	2.599E+07
2059	0	18,403,578	6.363E+04	5.095E+07	1.700E+04	2.548E+07
2060	0	18,403,578	6.237E+04	4.994E+07	1.666E+04	2.497E+07
2061	0	18,403,578	6.113E+04	4.895E+07	1.633E+04	2.448E+07
2062	0	18,403,578	5.992E+04	4.798E+07	1.601E+04	2.399E+07
2063	0	18,403,578	5.874E+04	4.703E+07	1.569E+04	2.352E+07
2064	0	18,403,578	5.757E+04	4.610E+07	1.538E+04	2.305E+07
2065	0	18,403,578	5.643E+04	4.519E+07	1.507E+04	2.259E+07
2066	0	18,403,578	5.532E+04	4.429E+07	1.478E+04	2.215E+07
2067	0	18,403,578	5.422E+04	4.342E+07	1.448E+04	2.171E+07
2068	0	18,403,578	5.315E+04	4.256E+07	1.420E+04	2.128E+07
2069	0	18,403,578	5.209E+04	4.171E+07	1.392E+04	2.086E+07
2070	0	18,403,578	5.106E+04	4.089E+07	1.364E+04	2.044E+07
2071	0	18,403,578	5.005E+04	4.008E+07	1.337E+04	2.004E+07
2072	0	18,403,578	4.906E+04	3.929E+07	1.310E+04	1.964E+07
2073	0	18,403,578	4.809E+04	3.851E+07	1.285E+04	1.925E+07

(Source: LandGEM v. 3.02, 2005)

Table 10. Landfill gas and methane emissions according to LandGEM v. 3.02 – Santa Marta (Continued)

Year	Waste Accepted	Waste-In-Place	Total landfill gas		Methane	
	(Mg/year)	*(Mg)*	*(Mg/year)*	*(m^3/year)*	*(Mg/year)*	*(m^3/year)*
2074	0	18,403,578	4.714E+04	3.775E+07	1.259E+04	1.887E+07
2075	0	18,403,578	4.620E+04	3.700E+07	1.234E+04	1.850E+07
2076	0	18,403,578	4.529E+04	3.627E+07	1.210E+04	1.813E+07
2077	0	18,403,578	4.439E+04	3.555E+07	1.186E+04	1.777E+07
2078	0	18,403,578	4.351E+04	3.484E+07	1.162E+04	1.742E+07
2079	0	18,403,578	4.265E+04	3.415E+07	1.139E+04	1.708E+07
2080	0	18,403,578	4.181E+04	3.348E+07	1.117E+04	1.674E+07
2081	0	18,403,578	4.098E+04	3.281E+07	1.095E+04	1.641E+07
2082	0	18,403,578	4.017E+04	3.216E+07	1.073E+04	1.608E+07
2083	0	18,403,578	3.937E+04	3.153E+07	1.052E+04	1.576E+07
2084	0	18,403,578	3.859E+04	3.090E+07	1.031E+04	1.545E+07
2085	0	18,403,578	3.783E+04	3.029E+07	1.010E+04	1.515E+07
2086	0	18,403,578	3.708E+04	2.969E+07	9.904E+03	1.485E+07
2087	0	18,403,578	3.635E+04	2.910E+07	9.708E+03	1.455E+07
2088	0	18,403,578	3.563E+04	2.853E+07	9.516E+03	1.426E+07
2089	0	18,403,578	3.492E+04	2.796E+07	9.328E+03	1.398E+07
2090	0	18,403,578	3.423E+04	2.741E+07	9.143E+03	1.370E+07
2091	0	18,403,578	3.355E+04	2.687E+07	8.962E+03	1.343E+07
2092	0	18,403,578	3.289E+04	2.633E+07	8.784E+03	1.317E+07
2093	0	18,403,578	3.224E+04	2.581E+07	8.610E+03	1.291E+07
2094	0	18,403,578	3.160E+04	2.530E+07	8.440E+03	1.265E+07
2095	0	18,403,578	3.097E+04	2.480E+07	8.273E+03	1.240E+07
2096	0	18,403,578	3.036E+04	2.431E+07	8.109E+03	1.215E+07
2097	0	18,403,578	2.976E+04	2.383E+07	7.948E+03	1.191E+07
2098	0	18,403,578	2.917E+04	2.336E+07	7.791E+03	1.168E+07
2099	0	18,403,578	2.859E+04	2.289E+07	7.637E+03	1.145E+07
2100	0	18,403,578	2.802E+04	2.244E+07	7.486E+03	1.122E+07
2101	0	18,403,578	2.747E+04	2.200E+07	7.337E+03	1.100E+07
2102	0	18,403,578	2.693E+04	2.156E+07	7.192E+03	1.078E+07
2103	0	18,403,578	2.639E+04	2.113E+07	7.050E+03	1.057E+07
2104	0	18,403,578	2.587E+04	2.072E+07	6.910E+03	1.036E+07
2105	0	18,403,578	2.536E+04	2.030E+07	6.773E+03	1.015E+07
2106	0	18,403,578	2.486E+04	1.990E+07	6.639E+03	9.951E+06
2107	0	18,403,578	2.436E+04	1.951E+07	6.508E+03	9.754E+06
2108	0	18,403,578	2.388E+04	1.912E+07	6.379E+03	9.561E+06
2109	0	18,403,578	2.341E+04	1.874E+07	6.252E+03	9.372E+06

(Source: LandGEM v. 3.02, 2005)

Table 10. Landfill gas and methane emissions according to LandGEM v. 3.02 – Santa Marta (Continued)

Year	Waste Accepted	Waste-In-Place	Total landfill gas		Methane	
	(Mg/year)	(Mg)	(Mg/year)	(m^3/year)	(Mg/year)	(m^3/year)
2110	0	18,403,578	2.294E+04	1.837E+07	6.129E+03	9.186E+06
2111	0	18,403,578	2.249E+04	1.801E+07	6.007E+03	9.004E+06
2112	0	18,403,578	2.204E+04	1.765E+07	5.888E+03	8.826E+06
2113	0	18,403,578	2.161E+04	1.730E+07	5.772E+03	8.651E+06
2114	0	18,403,578	2.118E+04	1.696E+07	5.657E+03	8.480E+06
2115	0	18,403,578	2.076E+04	1.662E+07	5.545E+03	8.312E+06
2116	0	18,403,578	2.035E+04	1.630E+07	5.436E+03	8.148E+06
2117	0	18,403,578	1.995E+04	1.597E+07	5.328E+03	7.986E+06
2118	0	18,403,578	1.955E+04	1.566E+07	5.222E+03	7.828E+06
2119	0	18,403,578	1.916E+04	1.535E+07	5.119E+03	7.673E+06
2120	0	18,403,578	1.879E+04	1.504E+07	5.018E+03	7.521E+06
2121	0	18,403,578	1.841E+04	1.474E+07	4.918E+03	7.372E+06
2122	0	18,403,578	1.805E+04	1.445E+07	4.821E+03	7.226E+06
2123	0	18,403,578	1.769E+04	1.417E+07	4.725E+03	7.083E+06
2124	0	18,403,578	1.734E+04	1.389E+07	4.632E+03	6.943E+06
2125	0	18,403,578	1.700E+04	1.361E+07	4.540E+03	6.805E+06
2126	0	18,403,578	1.666E+04	1.334E+07	4.450E+03	6.671E+06
2127	0	18,403,578	1.633E+04	1.308E+07	4.362E+03	6.539E+06
2128	0	18,403,578	1.601E+04	1.282E+07	4.276E+03	6.409E+06
2129	0	18,403,578	1.569E+04	1.256E+07	4.191E+03	6.282E+06
2130	0	18,403,578	1.538E+04	1.232E+07	4.108E+03	6.158E+06
2131	0	18,403,578	1.508E+04	1.207E+07	4.027E+03	6.036E+06
2132	0	18,403,578	1.478E+04	1.183E+07	3.947E+03	5.916E+06
2133	0	18,403,578	1.448E+04	1.160E+07	3.869E+03	5.799E+06
2134	0	18,403,578	1.420E+04	1.137E+07	3.792E+03	5.684E+06
2135	0	18,403,578	1.392E+04	1.114E+07	3.717E+03	5.572E+06
2136	0	18,403,578	1.364E+04	1.092E+07	3.644E+03	5.461E+06
2137	0	18,403,578	1.337E+04	1.071E+07	3.571E+03	5.353E+06
2138	0	18,403,578	1.311E+04	1.049E+07	3.501E+03	5.247E+06
2139	0	18,403,578	1.285E+04	1.029E+07	3.431E+03	5.143E+06
2140	0	18,403,578	1.259E+04	1.008E+07	3.363E+03	5.042E+06
2141	0	18,403,578	1.234E+04	9.883E+06	3.297E+03	4.942E+06
2142	0	18,403,578	1.210E+04	9.688E+06	3.232E+03	4.844E+06

(Source: LandGEM v. 3.02, 2005)

9.1.3 Santiago Poniente

Table 11. Landfill gas emissions according to Weber and Doedens – Santiago Poniente

Year	Waste acepted (tons)	Landfill gas production (m^3/year)
2002	85,135	469,140.55
2003	463,643	2,992,351.03
2004	435,940	5,192,318.17
2005	451,396	7,328,724.96
2006	480,000	9,478,321.19
2007	560,675	11,927,154.93
2008	663,798	14,778,696.68
2009	687,031	17,565,483.16
2010	711,077	20,296,372.30
2011	735,965	22,979,783.00
2012	761,723	25,623,719.26
2013	788,384	28,235,825.82
2014	815,977	30,823,390.40
2015	844,536	33,393,395.39
2016	874,095	35,952,538.46
2017	904,688	38,507,251.85
2018	936,352	41,063,736.84
2019	969,125	43,627,984.86
2020	1,003,044	46,205,786.16
2021	1,038,151	48,802,770.99
2022	1,074,486	51,424,409.38
2023	1,112,093	54,076,044.02
2024	1,151,016	56,762,898.84
2025	1,191,302	59,490,103.64
2026	0	55,468,204.98
2027	0	51,718,211.53
2028	0	48,221,740.80
2029	0	44,961,653.11
2030	0	41,921,967.49
2031	0	39,087,783.41
2032	0	36,445,207.68
2033	0	33,981,286.41
2034	0	31,683,941.44
2035	0	29,541,911.19

(Source: elaborated model)

Table 11. Landfill gas emissions according to Weber and Doedens – Santiago Poniente (Continued)

Year	Waste acepted (tons)	Landfill gas production (m^3/year)
2036	0	27,544,695.42
2037	0	25,682,503.78
2038	0	23,946,207.81
2039	0	22,327,296.17
2040	0	20,817,832.96
2041	0	19,410,418.80
2042	0	18,098,154.53
2043	0	16,874,607.44
2044	0	15,733,779.69
2045	0	14,670,078.94
2046	0	13,678,290.94
2047	0	12,753,553.94
2048	0	11,891,334.88
2049	0	11,087,407.15
2050	0	10,337,829.91
2051	0	9,638,928.72
2052	0	8,987,277.57
2053	0	8,379,682.06
2054	0	7,813,163.77
2055	0	7,284,945.61
2056	0	6,792,438.26
2057	0	6,333,227.46
2058	0	5,905,062.14
2059	0	5,505,843.45
2060	0	5,133,614.40
2061	0	4,786,550.34
2062	0	4,462,949.96
2063	0	4,161,226.96
2064	0	3,879,902.30
2065	0	3,617,596.93
2066	0	3,373,025.02
2067	0	3,144,987.68
2068	0	2,932,367.08
2069	0	2,734,120.94
2070	0	2,549,277.47
2071	0	2,376,930.56

(Source: elaborated model)

Table 11. Landfill gas emissions according to Weber and Doedens – Santiago Poniente (Continued)

Year	Waste acepted (tons)	Landfill gas production (m^3/year)
2072	0	2,216,235.36
2073	0	2,066,404.15
2074	0	1,926,702.46
2075	0	1,796,445.47
2076	0	1,674,994.65
2077	0	1,561,754.66
2078	0	1,456,170.40
2079	0	1,357,724.28
2080	0	1,265,933.73
2081	0	1,180,348.78
2082	0	1,100,549.91

(Source: elaborated model)

Table 12. Methane emissions avoided according CDM methodological tool - Santiago Poniente

Year	Amount of waste (tons)	Methane emission avoided (tCO_2e)
2002	85,135	4202.6972
2003	463,643	26682.0855
2004	435,940	45609.5095
2005	451,396	63460.6743
2006	480,000	80989.2161
2007	560,675	100796.9751
2008	663,798	123770.6191
2009	687,031	145658.7305
2010	711,077	166606.9282
2011	735,965	186748.1124
2012	761,723	206203.6511
2013	788,384	225084.7476
2014	815,977	243493.2309
2015	844,536	261522.7132
2016	874,095	279259.3884
2017	904,688	296782.7532
2018	936,352	314166.4057
2019	969,125	331478.6681
2020	1,003,044	348783.0502
2021	1,038,151	366138.9633
2022	1,074,486	383602.0204
2023	1,112,093	401224.6022
2024	1,151,016	419056.1718
2025	1,191,302	437143.7055
2026	0	394664.8748
2027	0	356313.8653
2028	0	321689.5617
2029	0	290429.8266
2030	0	262207.7128
2031	0	236728.0435
2032	0	213724.3256
2033	0	192955.9620
2034	0	174205.7351
2035	0	157277.5355
2036	0	141994.3100

(Source: elaborated model)

Table 12. Methane emissions avoided according CDM methodological tool - Santiago Poniente (Continued)

Year	Amount of waste (tons)	Methane emission avoided (tCO_2e)
2037	0	128196.2107
2038	0	115738.9225
2039	0	104492.1539
2040	0	94338.2744
2041	0	85171.0840
2042	0	76894.7025
2043	0	69422.5669
2044	0	62676.5257
2045	0	56586.0216
2046	0	51087.3538
2047	0	46123.0113
2048	0	41641.0719
2049	0	37594.6588
2050	0	33941.4502
2051	0	30643.2370
2052	0	27665.5232
2053	0	24977.1645
2054	0	22550.0433
2055	0	20358.7743
2056	0	18380.4387
2057	0	16594.3452
2058	0	14981.8128
2059	0	13525.9760
2060	0	12211.6081
2061	0	11024.9621
2062	0	9953.6268
2063	0	8986.3970
2064	0	8113.1564
2065	0	7324.7717
2066	0	6612.9972
2067	0	5970.3884
2068	0	5390.2242
2069	0	4866.4367
2070	0	4393.5475
2071	0	3966.6106

(Source: elaborated model)

Table 12. Methane emissions avoided according CDM methodological tool - Santiago Poniente (Continued)

Year	Amount of waste (tons)	Methane emission avoided (tCO_2e)
2072	0	3581.1608
2073	0	3233.1665
2074	0	2918.9880
2075	0	2635.3394
2076	0	2379.2540
2077	0	2148.0533
2078	0	1939.3192
2079	0	1750.8686
2080	0	1580.7303
2081	0	1427.1251

(Source: elaborated model)

Table 13. Landfill gas and methane emissions according to LandGEM v. 3.02 – Santiago Poniente

Year	Waste Accepted	Waste-In-Place	Total landfill gas		Methane	
	(Mg/year)	(Mg)	(Mg/year)	(m^3/year)	(Mg/year)	(m^3/year)
2002	85,135	0	0	0	0	0
2003	463,643	85,135	8.478E+02	7.172E+05	1.914E+02	2.869E+05
2004	435,940	548,778	5.448E+03	4.609E+06	1.230E+03	1.843E+06
2005	451,396	984,718	9.681E+03	8.190E+06	2.186E+03	3.276E+06
2006	480,000	1,436,114	1.398E+04	1.183E+07	3.157E+03	4.732E+06
2007	560,675	1,916,114	1.849E+04	1.564E+07	4.174E+03	6.256E+06
2008	663,798	2,476,789	2.370E+04	2.005E+07	5.351E+03	8.021E+06
2009	687,031	3,140,587	2.985E+04	2.525E+07	6.738E+03	1.010E+07
2010	711,077	3,827,618	3.610E+04	3.054E+07	8.149E+03	1.221E+07
2011	735,965	4,538,695	4.246E+04	3.592E+07	9.586E+03	1.437E+07
2012	761,723	5,274,660	4.895E+04	4.141E+07	1.105E+04	1.656E+07
2013	788,384	6,036,383	5.557E+04	4.701E+07	1.254E+04	1.880E+07
2014	815,977	6,824,767	6.232E+04	5.272E+07	1.407E+04	2.109E+07
2015	844,536	7,640,744	6.921E+04	5.855E+07	1.562E+04	2.342E+07
2016	874,095	8,485,280	7.625E+04	6.450E+07	1.721E+04	2.580E+07
2017	904,688	9,359,375	8.344E+04	7.059E+07	1.884E+04	2.824E+07
2018	936,352	10,264,063	9.080E+04	7.681E+07	2.050E+04	3.072E+07
2019	969,125	11,200,415	9.833E+04	8.318E+07	2.220E+04	3.327E+07
2020	1,003,044	12,169,540	1.060E+05	8.969E+07	2.394E+04	3.588E+07
2021	1,038,151	13,172,584	1.139E+05	9.637E+07	2.572E+04	3.855E+07
2022	1,074,486	14,210,735	1.220E+05	1.032E+08	2.754E+04	4.128E+07
2023	1,112,093	15,285,221	1.303E+05	1.102E+08	2.941E+04	4.409E+07
2024	1,151,016	16,397,314	1.388E+05	1.174E+08	3.133E+04	4.696E+07
2025	1,191,302	17,548,330	1.475E+05	1.248E+08	3.330E+04	4.991E+07
2026	0	18,739,632	1.564E+05	1.323E+08	3.531E+04	5.293E+07
2027	0	18,739,632	1.533E+05	1.297E+08	3.462E+04	5.189E+07
2028	0	18,739,632	1.503E+05	1.271E+08	3.393E+04	5.086E+07
2029	0	18,739,632	1.473E+05	1.246E+08	3.326E+04	4.985E+07
2030	0	18,739,632	1.444E+05	1.222E+08	3.260E+04	4.886E+07
2031	0	18,739,632	1.415E+05	1.197E+08	3.195E+04	4.790E+07
2032	0	18,739,632	1.387E+05	1.174E+08	3.132E+04	4.695E+07
2033	0	18,739,632	1.360E+05	1.150E+08	3.070E+04	4.602E+07
2034	0	18,739,632	1.333E+05	1.128E+08	3.009E+04	4.511E+07
2035	0	18,739,632	1.307E+05	1.105E+08	2.950E+04	4.421E+07
2036	0	18,739,632	1.281E+05	1.083E+08	2.891E+04	4.334E+07
2037	0	18,739,632	1.255E+05	1.062E+08	2.834E+04	4.248E+07

(Source: LandGEM v. 3.02, 2005)

Table 13. Landfill gas and methane emissions according to LandGEM v. 3.02 – Santiago Poniente (Continued)

Year	Waste Accepted	Waste-In-Place	Total landfill gas		Methane	
	(Mg/year)	(Mg)	(Mg/year)	(m^3/year)	(Mg/year)	(m^3/year)
2038	0	18,739,632	1.231E+05	1.041E+08	2.778E+04	4.164E+07
2039	0	18,739,632	1.206E+05	1.020E+08	2.723E+04	4.081E+07
2040	0	18,739,632	1.182E+05	1.000E+08	2.669E+04	4.001E+07
2041	0	18,739,632	1.159E+05	9.804E+07	2.616E+04	3.921E+07
2042	0	18,739,632	1.136E+05	9.610E+07	2.564E+04	3.844E+07
2043	0	18,739,632	1.113E+05	9.419E+07	2.514E+04	3.768E+07
2044	0	18,739,632	1.091E+05	9.233E+07	2.464E+04	3.693E+07
2045	0	18,739,632	1.070E+05	9.050E+07	2.415E+04	3.620E+07
2046	0	18,739,632	1.049E+05	8.871E+07	2.367E+04	3.548E+07
2047	0	18,739,632	1.028E+05	8.695E+07	2.320E+04	3.478E+07
2048	0	18,739,632	1.007E+05	8.523E+07	2.274E+04	3.409E+07
2049	0	18,739,632	9.875E+04	8.354E+07	2.229E+04	3.342E+07
2050	0	18,739,632	9.680E+04	8.189E+07	2.185E+04	3.275E+07
2051	0	18,739,632	9.488E+04	8.027E+07	2.142E+04	3.211E+07
2052	0	18,739,632	9.300E+04	7.868E+07	2.100E+04	3.147E+07
2053	0	18,739,632	9.116E+04	7.712E+07	2.058E+04	3.085E+07
2054	0	18,739,632	8.936E+04	7.559E+07	2.017E+04	3.024E+07
2055	0	18,739,632	8.759E+04	7.409E+07	1.977E+04	2.964E+07
2056	0	18,739,632	8.585E+04	7.263E+07	1.938E+04	2.905E+07
2057	0	18,739,632	8.415E+04	7.119E+07	1.900E+04	2.848E+07
2058	0	18,739,632	8.249E+04	6.978E+07	1.862E+04	2.791E+07
2059	0	18,739,632	8.085E+04	6.840E+07	1.825E+04	2.736E+07
2060	0	18,739,632	7.925E+04	6.704E+07	1.789E+04	2.682E+07
2061	0	18,739,632	7.768E+04	6.572E+07	1.754E+04	2.629E+07
2062	0	18,739,632	7.615E+04	6.441E+07	1.719E+04	2.577E+07
2063	0	18,739,632	7.464E+04	6.314E+07	1.685E+04	2.526E+07
2064	0	18,739,632	7.316E+04	6.189E+07	1.652E+04	2.476E+07
2065	0	18,739,632	7.171E+04	6.066E+07	1.619E+04	2.427E+07
2066	0	18,739,632	7.029E+04	5.946E+07	1.587E+04	2.378E+07
2067	0	18,739,632	6.890E+04	5.828E+07	1.555E+04	2.331E+07
2068	0	18,739,632	6.753E+04	5.713E+07	1.525E+04	2.285E+07
2069	0	18,739,632	6.620E+04	5.600E+07	1.494E+04	2.240E+07
2070	0	18,739,632	6.489E+04	5.489E+07	1.465E+04	2.196E+07
2071	0	18,739,632	6.360E+04	5.380E+07	1.436E+04	2.152E+07
2072	0	18,739,632	6.234E+04	5.274E+07	1.407E+04	2.110E+07
2073	0	18,739,632	6.111E+04	5.169E+07	1.380E+04	2.068E+07

(Source: LandGEM v. 3.02, 2005)

Table 13. Landfill gas and methane emissions according to LandGEM v. 3.02 – Santiago Poniente (Continued)

Year	Waste Accepted	Waste-In-Place	Total landfill gas		Methane	
	(Mg/year)	(Mg)	(Mg/year)	(m^3/year)	(Mg/year)	(m^3/year)
2074	0	18,739,632	5.990E+04	5.067E+07	1.352E+04	2.027E+07
2075	0	18,739,632	5.871E+04	4.967E+07	1.325E+04	1.987E+07
2076	0	18,739,632	5.755E+04	4.868E+07	1.299E+04	1.947E+07
2077	0	18,739,632	5.641E+04	4.772E+07	1.273E+04	1.909E+07
2078	0	18,739,632	5.529E+04	4.677E+07	1.248E+04	1.871E+07
2079	0	18,739,632	5.420E+04	4.585E+07	1.224E+04	1.834E+07
2080	0	18,739,632	5.312E+04	4.494E+07	1.199E+04	1.798E+07
2081	0	18,739,632	5.207E+04	4.405E+07	1.176E+04	1.762E+07
2082	0	18,739,632	5.104E+04	4.318E+07	1.152E+04	1.727E+07
2083	0	18,739,632	5.003E+04	4.232E+07	1.129E+04	1.693E+07
2084	0	18,739,632	4.904E+04	4.149E+07	1.107E+04	1.659E+07
2085	0	18,739,632	4.807E+04	4.066E+07	1.085E+04	1.627E+07
2086	0	18,739,632	4.712E+04	3.986E+07	1.064E+04	1.594E+07
2087	0	18,739,632	4.618E+04	3.907E+07	1.043E+04	1.563E+07
2088	0	18,739,632	4.527E+04	3.830E+07	1.022E+04	1.532E+07
2089	0	18,739,632	4.437E+04	3.754E+07	1.002E+04	1.501E+07
2090	0	18,739,632	4.349E+04	3.679E+07	9.819E+03	1.472E+07
2091	0	18,739,632	4.263E+04	3.607E+07	9.624E+03	1.443E+07
2092	0	18,739,632	4.179E+04	3.535E+07	9.434E+03	1.414E+07
2093	0	18,739,632	4.096E+04	3.465E+07	9.247E+03	1.386E+07
2094	0	18,739,632	4.015E+04	3.397E+07	9.064E+03	1.359E+07
2095	0	18,739,632	3.936E+04	3.329E+07	8.884E+03	1.332E+07
2096	0	18,739,632	3.858E+04	3.263E+07	8.709E+03	1.305E+07
2097	0	18,739,632	3.781E+04	3.199E+07	8.536E+03	1.279E+07
2098	0	18,739,632	3.706E+04	3.135E+07	8.367E+03	1.254E+07
2099	0	18,739,632	3.633E+04	3.073E+07	8.201E+03	1.229E+07
2100	0	18,739,632	3.561E+04	3.012E+07	8.039E+03	1.205E+07
2101	0	18,739,632	3.491E+04	2.953E+07	7.880E+03	1.181E+07
2102	0	18,739,632	3.421E+04	2.894E+07	7.724E+03	1.158E+07
2103	0	18,739,632	3.354E+04	2.837E+07	7.571E+03	1.135E+07
2104	0	18,739,632	3.287E+04	2.781E+07	7.421E+03	1.112E+07
2105	0	18,739,632	3.222E+04	2.726E+07	7.274E+03	1.090E+07
2106	0	18,739,632	3.158E+04	2.672E+07	7.130E+03	1.069E+07
2107	0	18,739,632	3.096E+04	2.619E+07	6.989E+03	1.048E+07
2108	0	18,739,632	3.035E+04	2.567E+07	6.850E+03	1.027E+07
2109	0	18,739,632	2.974E+04	2.516E+07	6.715E+03	1.006E+07

(Source: LandGEM v. 3.02, 2005)

Table 13. Landfill gas and methane emissions according to LandGEM v. 3.02 – Santiago Poniente (Continued)

Year	Waste Accepted	Waste-In-Place	Total landfill gas		Methane	
	(Mg/year)	(Mg)	(Mg/year)	(m^3/year)	(Mg/year)	(m^3/year)
2110	0	18,739,632	2.916E+04	2.466E+07	6.582E+03	9.866E+06
2111	0	18,739,632	2.858E+04	2.418E+07	6.451E+03	9.670E+06
2112	0	18,739,632	2.801E+04	2.370E+07	6.324E+03	9.479E+06
2113	0	18,739,632	2.746E+04	2.323E+07	6.198E+03	9.291E+06
2114	0	18,739,632	2.691E+04	2.277E+07	6.076E+03	9.107E+06
2115	0	18,739,632	2.638E+04	2.232E+07	5.955E+03	8.927E+06
2116	0	18,739,632	2.586E+04	2.187E+07	5.838E+03	8.750E+06
2117	0	18,739,632	2.535E+04	2.144E+07	5.722E+03	8.577E+06
2118	0	18,739,632	2.484E+04	2.102E+07	5.609E+03	8.407E+06
2119	0	18,739,632	2.435E+04	2.060E+07	5.498E+03	8.240E+06
2120	0	18,739,632	2.387E+04	2.019E+07	5.389E+03	8.077E+06
2121	0	18,739,632	2.340E+04	1.979E+07	5.282E+03	7.917E+06
2122	0	18,739,632	2.293E+04	1.940E+07	5.177E+03	7.761E+06
2123	0	18,739,632	2.248E+04	1.902E+07	5.075E+03	7.607E+06
2124	0	18,739,632	2.204E+04	1.864E+07	4.974E+03	7.456E+06
2125	0	18,739,632	2.160E+04	1.827E+07	4.876E+03	7.309E+06
2126	0	18,739,632	2.117E+04	1.791E+07	4.779E+03	7.164E+06
2127	0	18,739,632	2.075E+04	1.756E+07	4.685E+03	7.022E+06
2128	0	18,739,632	2.034E+04	1.721E+07	4.592E+03	6.883E+06
2129	0	18,739,632	1.994E+04	1.687E+07	4.501E+03	6.747E+06
2130	0	18,739,632	1.954E+04	1.653E+07	4.412E+03	6.613E+06
2131	0	18,739,632	1.916E+04	1.621E+07	4.325E+03	6.482E+06
2132	0	18,739,632	1.878E+04	1.588E+07	4.239E+03	6.354E+06
2133	0	18,739,632	1.841E+04	1.557E+07	4.155E+03	6.228E+06
2134	0	18,739,632	1.804E+04	1.526E+07	4.073E+03	6.105E+06
2135	0	18,739,632	1.768E+04	1.496E+07	3.992E+03	5.984E+06
2136	0	18,739,632	1.733E+04	1.466E+07	3.913E+03	5.865E+06
2137	0	18,739,632	1.699E+04	1.437E+07	3.836E+03	5.749E+06
2138	0	18,739,632	1.665E+04	1.409E+07	3.760E+03	5.635E+06
2139	0	18,739,632	1.632E+04	1.381E+07	3.685E+03	5.524E+06
2140	0	18,739,632	1.600E+04	1.354E+07	3.612E+03	5.414E+06
2141	0	18,739,632	1.568E+04	1.327E+07	3.541E+03	5.307E+06
2142	0	18,739,632	1.537E+04	1.301E+07	3.471E+03	5.202E+06

(Source: LandGEM v. 3.02, 2005)

9.2 Interviews guide-questions

The interviews were informal and open, each one depended on the available information in the institution made, this mean that each interview was on the area of each institution interviewed.

9.2.1 Ingeniería Alemana - 09.03.2010

1. Which is the difference between Domiciliary Solid Waste and Assimilable Solid Waste?
2. Which is the difference between the environmental qualification and a sanitary authorization?
3. Where is available a list of characterization of solid waste of the metropolitan region?
4. The Comunas that are not located in the big Santiago, also deposit their waste in the three main landfills of the region?
5. Are the municipalities in charge of their own waste management?
6. Which is the function of the transfer station of the landfills?
7. If the separation of waste existed, would it happened in the transfer station?
8. Is there any recycling in the Metropolitan Region?
9. Are there any informal collectors in the landfills of the Metropolitan Region?
10. Which institutions supervise the landfills?

9.2.2 Comisión Nacional del Medioambiente – 10.03.2010

1. Which is the main function of CONAMA?
2. How does the waste management works, from recollection to final disposition?
3. The companies in charge of the landfills are free to use the waste as they please?
4. How many landfills are private?
5. Which are the waste separation programs that exist in the metropolitan region?
6. Which is the collecting efficiency of the waste in the metropolitan region?
7. How are settled the prices for the waste management services?

9.2.3 CONAMA – Departamento de estudios – 12.03.2010

1. Which is the National Designed Authority in Chile?
2. How does the National Designed Authority works?
3. How does ProChile function with the CDM market in Chile?
4. Can a municipality participate in the CDM?
5. What does the grouping means, for small scale projects?
6. How do the supporting founds work for the project developers?

9.2.4 CORFO – Consejo de Producción Limpia - 19.03.2010

1. Which are the basic functions of the Consejo de Producción Limpia?
2. The goals of the clean production policy are accomplished?

3. How do the clean production agreements work?
4. How does the assessment for companies work?
5. How is the CDM involved with the Clean Production Agreements?
6. Which are the fees applicable?
7. Is CORFO planning to participate with renewable energies?
8. How can somebody participate in a Clean Production Agreements?
9. How do you determine the size of the companies that can participate with the Clean Production Agreements?

9.2.5 ProChile – Medio Ambiente y Calidad – 01.04.2010

1. Who is the National Designated Authority?
2. What is the function of ProChile within the Carbon market?
3. ProChile is the international contact for Chile in the Carbon market?
4. Which are the institutions involved in the CDM project cycle?
5. How does the CDM project cycle starts in Chile?
6. How do the supporting founds work for the project developers?
7. Which is the founding for the development of Project Design Documents?
8. Is there a minimum size for the projects of the Clean Development Mechanism?