Fachhochschule Köln
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UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ
FACULTADES DE CIENCIAS QUÍMICAS, INGENIERÍA Y MEDICINA
PROGRAMAS MULTIDISCIPLINARIOS DE POSGRADO EN CIENCIAS AMBIENTALES
AND
COLOGNE UNIVERSITY OF APPLIED SCIENCES
INSTITUTE FOR TECHNOLOGY AND RESOURCES MANAGEMENT IN THE TROPICS AND SUBTROPICS

CONVERTING URBAN ORGANIC WASTE TO ENERGY - A STUDY OF THE BIOGAS POTENTIAL IN SAN LUIS POTOSÍ, MEXICO

THESIS TO OBTAIN THE DEGREE OF
MAESTRÍA EN CIENCIAS AMBIENTALES
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UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ
AND
MASTER OF SCIENCE
"TECHNOLOGY AND RESOURCES MANAGEMENT IN THE TROPICS AND SUBTROPICS
FOCUS AREA "ENVIRONMENTAL AND RESOURCES MANAGEMENT"
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DECLARATION

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Hereby I declare on oath that this work in hand has been made independently and without the use of any other than the aids given below. The thoughts taken directly or indirectly from external sources are made recognisable as such. This work was not presented to any other examination authority either in same or similar form and until now has not been published. Further I agree to a later publication of this Master Thesis, may it be in parts or as complete work within the ITT or UASLP publications or within the scope of ITT's or UASLP´s public relation, always when the reference is cited.

Cologne July 1st, 2012 Signature ……………………………………..

PREFACE

"One Man´s Trash Is Another Man´s Treasure"
–James Madison

Our everyday life is dominated by the consumption of products, of which we forgot their natural origin. The every morning cup of coffee accompanied by the newspapers before driving to work. The lights we switch on, the plates we eat from, the beds we sleep in. Do we ever consider where these daily used items and services come from - and where they go?

The fact that most products sooner or later finish in the trash is no big news, but today we rediscover that most wastes in fact are valuable resources at the wrong place that could be used more reasonably. Everything we do requires energy and today that is also inseparably connected to climate and nature protection. The energetic utilisation of natural resources in times of rising oil prices and the boom of renewable energies seeks for new ideas.

Approaches without an exploitation of natural resources like the conversion of waste to energy – a matter we have too much of to a matter we urgently need- are just as fantastic and logical as the designs of nature itself, where trees convert a matter we have too much of (CO_2) to a matter we actually need to survive (oxygen)!

My motivation for the present Master Thesis is to call attention for obvious simple solutions that nature has prepared, to solve problems we face today and remind how a sensible use of natural resources can convert trash into a treasure and benefit our lives.

ACKNOWLEDGEMENT

At this point I declare my gratitude to all the people who collaborated in some form to this investigation. I am very grateful to the citizens of San Luis Potosí, who unwittingly provided the samples to this study and I wish to express my deepest respect and thankfulness to all the garbage collectors in the city. This thesis is dedicated to all pepenadores of Mexico´s dumpsites.

First of all, I would like to thank the staff and professors from the Autonomous University of San Luis Potosí (UASLP) and the Cologne University of Applied Sciences (CUAS) for the preparation, education and administration during my studies.
I especially thank my supervisor Prof. Dr. Juan Manuel Pinos Rodríguez for his interest in my thesis, his methodological and scientific help and for providing the investigation´s setting. My gratitude belongs to my supervisor Prof. Dr. Sabine Schlüter for her scientific support, revision, emendations, recommendations and advices. Special thanks go to my assessor Prof. Dr. Juan Carlos García López for his organisational help and for always being susceptible to my questions.

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Furthermore, I would like to thank Dr. Sören Rüd from the GIZ in Mexico City, Lic. Mayra Denise Govea Tello, General Director of Ecology and Urban Sanitation of the Municipality SLP and Dir. Juan Manuel Miramontes from Red Ambiental for their time and the provision of information on waste management in Mexico and for taking me to the local dumpsite Peñasco.
In particular, I want to express my gratitude to Cecilia Gonzalez Gonzalez, who helped me both with organisational matters and content. I very much appreciate her ideas, her encouragement and her friendship.
Thank you, Lena Di Carlo, Maria Clemencia Cerón and Frank Spandl for the help in editing and for the critical comments revising the document.

And finally my thanks belong to my family and friends for always being there for me, loving me and believing in me.

ABSTRACT

One of the most pressing current problems in Mexico is the continuous growth in waste generation and the lack of an adequate waste management system. Urban wastes mostly end up at dumpsites and uncontrolled landfills, where they emit dangerous GHGs to the atmosphere and cause problems for health and environment. Mexico, being a main oil producer, depends largely on oil and hydrocarbons for its energy supply. It is Mexico´s goal to achieve 8% share of renewable energy sources by 2012. The strategy of converting waste into energy can also help mitigate environmental deterioration, energy shortages and waste processing costs. The city of San Luis Potosí produced 302.000 tons of waste in 2009. Projections for 2014 for the local sanitary landfill Peñasco showed a biogas potential of 1.290m^3 per hour that could be recovered and provide 2.1MW electrical capacity to the end users in SLP.

Keywords: Waste to Energy, Biogas, Landfill gas, Mexico

RESUMEN

Uno de los problemas actuales más apremiantes en México es el continuo crecimiento en la generación de residuos y la falta de un sistema adecuado de manejo de residuos. La mayoría de los desechos urbanos terminan en rellenos y vertederos incontrolados, donde emiten peligrosos gases de efecto invernadero a la atmosfera y causan problemas para la salud y el medio ambiente. México, al ser un principal productor de petróleo, depende en gran medida del petróleo y los hidrocarburos para su abastecimiento energético. Es el objetivo de alcanzar el 8% de fuentes de energías renovables para 2012 en México. La estrategia de convertir desechos en energía también puede ayudar a mitigar el deterioro ambiental, escasez de energía y los costos de tratamiento de residuos. La ciudad de San Luis Potosí produjo 302.000 de toneladas de residuos en 2009. Las proyecciones para 2014 para el relleno sanitario local Peñasco mostraron un potencial de biogás de 1.290m^3 por hora, que podrían ser recuperados y proporcionar una capacidad eléctrica de 2.1MW a los usuarios finales en SLP.

ZUSAMMENFASSUNG

Eines der dringlichsten aktuellen Probleme in Mexiko ist das kontinuierliche Abfallwachstum und der Mangel eines adäquaten Abfallmanagements. Städtische Abfälle werden meist offen entsorgt oder landen auf unkontrollierten Deponien, wo sie gefährliche Treibhausgase an die Atmosphäre emittieren und Probleme für Gesundheit und Umwelt verursachen. Mexikos Energieversorgung hängt derzeit vor allem von Öl und Kohlenwasserstoffen ab. Ziel ist, bis 2012 einen Anteil von 8% Erneuerbarer Energien im Stromnetz zu erreichen. Das Konzept der Umwandlung von Abfall in Energie kann hierzu einen wichtigen Beitrag leisten und weiterhin zum Umweltschutz und zu Kostenminimierung in der Abfallbehandlung beitragen. In der Stadt San Luis Potosí wurden im Jahr 2009 302.000 Tonnen Abfall produziert. Hochrechnungen für 2014 für die lokale Mülldeponie Peñasco zeigten ein nutzbares Biogas-Potenzial von 1.290m^3 pro Stunde, was eine Stromkapazität von 2,1MW für den Endbenutzer bedeuten könnte.

TABLES

FIGURES

ABBREVIATIONS

3Cs	Confine, Compact, Cover
3Rs	Reduce, Reuse, Recycle
AAU	Assigned Amount Unit
AIE	Accredited Independent Entity
AMDEE	Asociación Mexicana de Energía Eólica
AMEE	Asociación Mexicana de Economía Energética
AMV	Ampere Mega Volt
ANES	Asociación Nacional de Energía Solar
BANCOMEXT	Banco de Comercio Exterior
BANOBRAS	Banco Nacional de Obras y Servicios Públicos
BENLESA	Bioenergía de Nuevo León, S. A. de C. V.
BMW	Biomedical Waste
BOO	built-own-operate
BtL	Biomass to Liquid
C&D	Construction and Demolition
C&I	Commercial and Industrial
CBD	Convention on Biological Diversity
CC	Climate Change
CCM	Climate Change Mitigation
CDM	Clean Development Mechanism
CECODES	Centro de Ecodesarrollo
CER	Certified Emissions Reduction
CFE	Comisión Federal de Electricidad
cfm	cubic foot per minute
CHP LFGE	Combined Heat and Power Landfill Gas Energy
CHP	Combined Heat and Power
CMAP	Clasificación Mexicana de Actividades y Productos
CNA	Comisión Nacional del Agua
CNSNS	National Nuclear Safety and Safeguards
CO_2	Carbondioxide
CO_2e	Carbondioxide equivalent
COA	Cedula de Operación Anual
COCEF	Comisión de Cooperación Ecológica Fronteriza México-USA
CONAE	Comisión Nacional para el Ahorro de la Energía
CRE	Comisión Regulatoria de Energía
CSD	Commission on Sustainable Development
CUAS	Cologne University of Applied Sciences
DBOO	design-built-own-operate
DC	Developing Countries
DED	Deutscher Entwicklungsdienst
DF	Distrito Federal de Mexico
DNA	Designated National Authority

DSW	Domestic Solid Waste
E&P	Execution and Production
EB	Executive Board
EE	Energy Efficiency
EEIS	Environmental and Energy Study Institute
EEP	Extern Energy Producers
EIA	Energy Information Administration
EIA	Environmental Impact Assessment
EJ	exajoule
EMC	Environmental Municipal Commission
ENREM	Environment and Resources Management
EPA	(US) Environmental Protection Agency
EPR	Extended Producer Responsibility
ET	Evapotranspiration
EU	European Union
EU ETS	European Union Emissions Trading Scheme
F	Fire Risk Factor
FAO	Food and Agriculture Organisation
FDW	Fast Decay Waste
FIRCO	Fideicomiso de Riesgo Compartido
FML	Flexible Membrane Liners
FNR	Fachagentur Nachwachsende Rohstoffe
FONADIN	Fondo Nacional de Infraestructura
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse Gas
GIS	Green Investment Scheme
GIZ	Gesellschaft für internationale Zusammenarbeit und Entwicklung
GJ	Gigajoule
GMI	Global Methane Initiative
GW	Giga Watt
HDI	Human Development Index
HDPE	High Density Polyethylene
HH	Household
hhv	higher heating value
HHW	Household Hazardous Waste
HSW	Hazardous Solid Waste
IAEA	International Atomic Energy Agency
IC	Industrialised Countries
ICMA	International City/Country Management Association
ID	Identification
IET	International Emissions Trading
IIE	Instituto de Investigaciones Eléctricas

INAFED	Instituto Nacional para el Federalismo y el Desarrollo Municipal
INE	Instituto Nacional de Ecología
INEGI	Instituto Nacional de Estadística y Geografía
INIFAP	Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias
ININ	Instituto de Investigación Nuclear
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producer
ISIC	International Standard Industrial Classification
ISWM	Integrated Solid Waste Management
ISWMP	Integrated Solid Waste Management Programme
ITT	Institute for Technology in the Tropics and Subtropics
IWB	Itinerant Waste Buyer
JI	Joint Implementation
JV	Joint Venture
k	Methane Generation Rate Constant
KP	Kyoto Protocol
kV	kilo Volt
kWh	kilowatt hours
L.P. gas	Liquefied Petroleum gas
L_0	Potential Methane Generation Capacity
LA	Latin America
LAU	Licencia Ambiental Unica
LAERFTE	Ley Para el Aprovechamiento de Energías Renovables y el Financiamiento de la Transición Energética
LAFRE	Ley para el Aprovechamiento de las Fuentes Renovables de Energía
LED	Light Emitting Diode
LF	landfill
LFC	Luz y Fuerza del Centro
LFG	Landfill gas
LGA	Local Government Authority
LGEEPA	Ley General para el Equilibrio Ecológico y la Protección al Ambiente
LGPGIR	Ley General para la Prevención y Gestión Integral de los Residuos
LMOP	Landfill Methane Outreach Program
LSPEE	Ley del Servicio Público de Energía Eléctrica
LTS	Large Transfer Station
M2M	Methane to Markets
m^3/hr	cubic meters per hour
MCF	Methane Correction Factor
MDG	Millennium Development Goal
MFDW	Medium Fast Decay Waste
Mg	metric tons
mmBtu	Million British thermal unit

MRF	Materials Recovery Facility
MRV	Monitor, Report, Varify
MSDW	Medium Slow Decay Waste
MSW	Municipal Solid Waste
MtCO2eq	Million tons of CO_2 equivalent
MW	Megawatt
MWh	Megawatt hour
MX$	Mexican Pesos
NAMA	Nationally Appropriate Mitigation Actions
NEA	National Environment Agency
NGO	Non-Governmental Institution
NL	Nuevo Leon (Mexican State)
NMX	Norma Mexicana
NOC	Non-Objection Certificate
NOx	Nitrogen Oxide
OECD	Organisation for Economic Cooperation and Development
OGJ	Oil and Gas Journal
ORC	Organic Rankine Cycle
PAR	Participative Action Research
pbs	public broadcasting service
PEMEX	Petróleos Mexicanos
PEP	Pemex Exploration and Production
PET	Polyethylene Terephthalate
PGPB	Pemex Gas and Basic Petrochemicals
PMI	Pemex International
PMPCA	Programa Multidisciplinario de Posgrado en Ciencias Ambientales
ppb	parts per billion
PPP	Public Private Partnership
PPQ	Pemex Petrochemicals
PR	Pemex Refining
PROFEPA	Procuradería Federal de Proteccion al Ambiente
PSP	Private Sector Participation
PVEM	Partido Verde Ecologista de Mexico
R&D	Research and Development
RDBMS	Relational Database Management System
RDF	Refuse Derived Fuel
RE	Renewable Energy
RSW	Residential Solid Waste
RUA	Rapid Urban Appraisal
SDW	Slow Decay Waste
SE	Secretaria de Economía
SEDESOL	Secretaria de Desarrollo Social
SEDUE	Secretaria de Desarrollo Urbano y Ecología

SEGAM	Secretaria de Ecología y Gestion Ambiental
SEISA	Sistemas de Energía Internacional, S.A. de C.V.
SEMARNAP	Secretaría de Medio Ambiente, Recursos Naturales y Pesca
SEMARNAT	Secretaria del Medio Ambiente y Recursos Naturales
SENER	Secretaria de Energía
SI	spark ignited
SIMEPRODE	Sistema Integral para el Manejo Ecológico y Procesamiento de Desechos
SLP	San Luis Potosí
SMA	Subsecretaría de Mejoramiento del Ambiente
SME	Small and Medium-sized Enterprise
SPG	Strategic Planning Guide for Municipal Solid Waste Management
STPS	Secretaria del Trabajo y Previsión Social
STS	Small transfer station
SW	Solid Waste
SWM	Solid Waste Management
TC	Total Carbon
tCO2eq	tons of CO_2 equivalent
TIC	Total Inorganic Carbon
TOC	Total Organic Carbon
TPD	(metric) tonnes per day
TPY	(metric) tons per year
TWh	Terawatt hours
UASLP	Universidad Autónoma de San Luis Potosí
UN	United Nations
UNCRD	United Nations Centre for Regional Development
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework on Climate Change
USA	United States of America
USAID	United States Agency for International Development
USW	Urban Solid Waste
UWEP	Urban Waste Expertise Programme
v/v	Volume to volume
VCS	Voluntary Carbon Standard
VOC	Volatile Organic Compound
WB	World Bank
WHO	World Health Organisation
WREP	Waste and Resources Evidence Programme
WtE	Waste to Energy
WWF	World Wide Fund for Nature
ZW	Zero Waste

CONTENT

GENERAL INTRODUCTION

Achieving solutions to environmental problems that we face today requires long-term potential actions for sustainable development. In this regard, renewable energy resources appear to be one of the most efficient and effective solutions. On the one hand, around 1.3 billion people worldwide still have no access to electricity or rely on the use of animal power and non-commercial fuels (IAEA, 2009), when on the other hand they are suffering various environmental problems caused by improper waste management.

In 2005 a Mexican law for the exploitation of renewable energy sources (LAFRE by its Spanish name) came into force. The goal to achieve 8% share of renewable energies to the total electricity generation by 2012 cannot only be achieved by the improvement of energy efficiency and innovative technologies, but clearly by new ideas and strategies that have high capacity of providing energy. To sustainably make an effort in conservation and development work, big-scale mechanisms that are attached to international markets but can be easily applied in developing regions and directly improve people´s livelihood regarding local economic development, need to be found and supported.

"Globally, 140 billion metric tons of biomass is generated every year from agricultural, forestall and industrial activity" states the UNEP (2009). Also organic wastes like human excrements in sewages can be converted to energy, while the remains can be used as fertilisers when using modern treatment technologies. Uncontrolled waste- and wastewater disposal can cause severe problems for health and environment. Organic fraction of domestic wastes from the cities are valuable energy sources, whose potential, especially in developing countries, remain insufficiently used and studied.
Especially in developing countries where adequate waste management, recycling systems and regulating environmental policies are lacking, this is becoming a massive problem. Rotten waste organic biomass on unsecured open landfills emits methane and leachate, common open fire incinerations generate CO_2 and contribute to climate change, water and soil contamination and local air pollution instead of providing energy.

Population growth, rapid urbanisation and industrialisation processes cause a continuously generation of large amounts of wastes and complicates conservation plans and further development in the country.
Urban waste is of high value with respect to material and energy recovery. Biomass is a renewable resource that causes problems when not used. The challenge therefore is to convert biomass as a resource for energy and other productive uses. The energetic utilisation of wastes in times of rising oil prices and the strengthening of renewable energies is not only a popular conservation strategy but also in terms of development, health and economy lucrative.

RESEARCH QUESTION

The present thesis bases on information obtained during my studies in the international Master study program “Environment and Resources Management (ENREM), M.Sc.” that is held in Cooperation with the Agenda Ambiental of the Programa Multidisciplinario de Posgrado en Ciencias Ambientales (PMPCA) of the Universidad Autónoma de San Luis Potosí (UASLP), Mexico and the Institute for Technology and Resources Management in the Tropics and Subtropics (ITT) of the Cologne University of Applied Sciences (CUAS), Germany. During the first year from June 2010 until June 2011, the current situation at the study area in San Luis Potosí (SLP) was examined, including national policies on energy and waste management as well as existent projects on biogas recovery from wastes. The third semester was given at the ITT in Cologne, where the focus was on technical and political issues in respect to biogas and landfill gas. The final semester served for a three month field research in the city of SLP, where the urban solid waste (USW) management was intensively studied and possible waste to energy (WtE) implementation strategies were analysed. A detailed list of the activities accomplished for the master thesis research can be consulted in the Chronogram of Activities in the Annex.

The main goal of this investigation is to determine the potential of urban organic wastes that are generated in the city of SLP for the exploitation of biogas.

What is the biogas potential of urban organic wastes from
San Luis Potosí, Mexico?

OBJECTIVES

The thesis focuses on three specific questions that provide the background for the main general objective and for responding the research question.

Specific Objectives:

- Analyse the Current Waste and Energy Situation in Mexico
- Analyse the Waste Management in SLP
- Analyse Possible Waste to Energy Implementation Strategies for San Luis Potosí

General Objective:

- Analyse the Biogas Potential of Urban Organic Wastes in San Luis Potosí

In the first chapter of this thesis the first specific objective is addressed, presenting data on waste generation, recollection and disposal and facts about energy sources, capacity, distribution and consumption. Both sectors analysis end with a part about regulations, legislation and policies on waste management, respectively energy. This chapter acts as

a literature based review that provides the background for the investigation on the waste management in SLP, which will be focus of the second chapter and replies to specific objective number 2.
In chapter 3, the third specific objective will be analysed, determining how wastes can be converted into energy by presenting possible strategies, among recycling approaches, biogas technologies and implementation requirements.
Finally, in chapter 4, based on a theoretical case scenario, the calculated data results on the potential biogas yield for the city of SLP will serve as proposal for the generation of biogas from urban organic wastes in SLP and will be the final outcome of this investigation responding the research question and the general objective.

The main goal of this thesis is to show a strategy of internal solutions to environmental, social and economic problems by the promotion of the biogas potential from urban organic wastes, which comes along with the implementation of a proper waste management system, including a recycling system in order to promote conservation and development in San Luis Potosí, Mexico. This investigation showcases the work of waste management in a Mexican city and can serve as case study for other cities, where a waste management system, a landfill sanitation or/and the development of alternative energy sources are still in need of improvement.
The example provides up-to-date data and can be used to inform questions of waste and energy policies, good and bad practice, management, governance, financing and many other issues. It can help decision makers, practitioners and ordinary citizens to understand what happens to the generated wastes, understand the need of protecting the environment and inspire people in good communication with their neighbours, constituents and leaders, to consider their consumption and disposal habits and their own decisions for the next steps in developing a solution appropriate for their city´s particular circumstances and needs.
The focus is on processes and implementation requirements rather than technologies and the goal is to encourage initiatives to well-planned waste management strategies, the application of the 3Rs, reduce climate emissions and alternatives to generate energy.

CHAPTER 1: THE ENERGY AND WASTE SITUATION IN MEXICO: A REVIEW

1.1 INTRODUCTION

To have a background from which to analyse the possibilities of converting waste to energy inside the framework of the current energy and waste system in Mexico, a short review, even if it is superficial and panoramic, will provide the information on how has the initial situation of energy and waste generation, consumption and management been, as well as to serve for predictions about future trends in this regard.

One of the most pressing problems in Mexico at the beginning of the 21st century is the derivative energy consumption and waste generation in urban areas where extraction processes from resources such as mining, oil, forestry and others are conducted and are used as inputs in manufacturing industries (Cortinas de Nava, 2001). The problem referred to, has implications not only concerning the environment and health but is also of economic, commercial, technological, social and political matter and some of them may transcend national boundaries to become a global problem.

Mexico has also been involved in problems of large volumes of sludge from oil drilling activities and other wastes. Since Mexico became member of the Organisation for Cooperation and Development (OECD) it has industrialised rapidly and is today one of the countries that has signed the most trade agreements, both conditions that not at least influence energy and waste consumption and production patterns.

1.2 THE ENERGY SITUATION

Historically it cannot be overseen that during the years before the Mexican Independence from the Spanish Crown the main productive activities were agriculture and mining and it was not until the 1940s, years after the completion of the Revolution, when an accelerated industrialisation of the country began, which was even more concentrated in urban centres. The mining activities have generated lots of environmental liabilities and in many places environmental and health risks play an important role for conservation plans.

During the nineteenth century, hydraulic energy in forms of e.g. sugar mills was the main engine for the industrialisation of Mexico. During the last third of the century wheels were substituted by hydraulic turbines, leading to hydropower generation, which continued playing an important role in the internal energy supply, but its participation diminished during the first half of the twentieth century initiated by the growing use of fossil fuels and promoted, besides other factors, by the availability of oil-derived products and natural gas, which were cheap in those years (SENER and GTZ, 2006). Mexico, being oil producing country since the twentieth century, was 2009 ranked as the seventh biggest oil producer in the world (EIA, 2010) which is also reflected in the national energy mix.

At the beginning of the twentieth century, the energy sector was completely in the hands of private providers. In 1938, president Lázaro Cárdenas nationalised the 17 oil producing companies and founded PEMEX, until 1960 finally the electricity supplying companies were nationalised. After the company Luz y Fuerza del Centro (LFC), responsible for Mexico City and its surroundings was combined with the rest of the country, there has been only one monopole supplier, the Comisión Federal de Electricidad (CFE), which today covers 100% of the electricity network of Mexico (CIA, 2010).

1.2.1 ENERGY SOURCES

In 2009 Mexico was stated seventh largest producer of oil in the world (CIA, 2010), which is why oil still holds the biggest share (35%) in Mexican energy sources and the revenues still generate over 15% of Mexico's export earnings and makes it a crucial sector for Mexico's economy (EIA, 2010). Petroleos Mexicanos (Pemex) is Mexico's state-owned petroleum company and the monopolist supplier of all commercial gasoline (petrol/diesel) stations in the country. The government relies on earnings from the oil industry, including taxes and direct payments from Pemex, for about 40% of the total government revenues. Therefore, any decline in Pemex´s production has a direct effect on Mexico's overall fiscal balance (EIA, 2010). Mexico's proven oil reserves count with around 14 billion barrels; most of these heavy crudes are located offshore in the Gulf of Campeche in the southern part of the country (Weintraub, 2008). In 2008 oil production has declined 9,2% to 3,96 million barrels a day, while natural gas production increased by 14,2% to 6,92 cubic feet (Pemex, 2008). To meet the high levels of consumption Mexico had to start to import oil and continues in dependence with the USA.

According to the Oil and Gas Journal (OGJ), Mexico had 13.2 trillion cubic feet (Tcf) of proven natural gas reserves as of January 2010. The figure on sources for the national energy consumption is dominated to same parts by oil (35%) and natural gas (34%). Pemex itself is the single largest consumer of natural gas, representing around 40% of domestic consumption (EIA, 2010). Natural gas is a fossil fuel energy that is captured in the soil and is generated by the decomposition of organic matter trapped between rock layers.

Gas is steadily substituting fuel oil and coal for the Mexican electricity generation, but the demand on gasolines driven by the transport sector has increased nearly 50% in the last ten years (SENER, 2010b) and is likely to continue doing so. The current share of "clean energies" (that include hydropower and nuclear energy) was 20% by 2011 and the annual growth rate of 1.1% for this sources lies still below the 2.4% for the total installed capacity. Nuclear and wind energy are the main potential sources considered in the scenarios for 2026 (SENER, 2012).

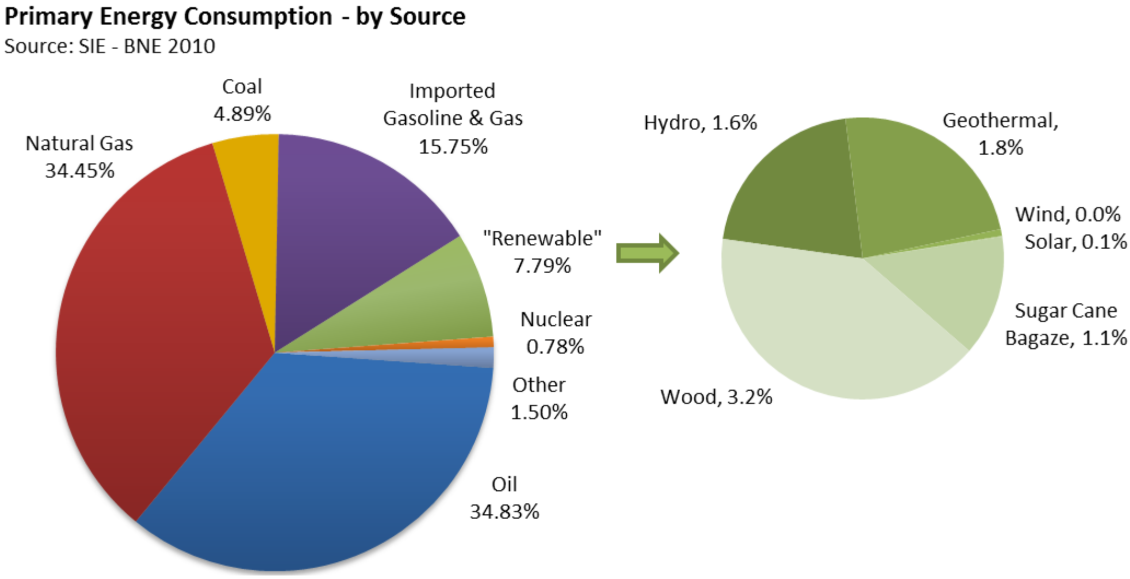

Figure 1: Mexico´s Primary Energy Consumption by Source (SIE-BNE, 2010)

According to SENER (2010b) the installed capacity of renewable energy (RE) sources by the end of 2011 was 2.4GW, corresponding to 3.88% of the total energy sources. Taking into account the recently installed windparks in Oaxaca, that operate since April 2012, this share would need to be summed up.

To big part the share of RE sources is biomass. Fuel wood represents between 8% and 10% of the final energy consumption, and 36% to 45% of the residential use. The National Forest Commission (CONAFOR, 2007) states that still around 25% of the Mexican population uses wood for cooking, in the rural sector up to 89%. Domestic use of wood for self-consumption accounts for 24.9 Mm^3 of wood per year and together with 6 Mm^3 used by small industries needs to be considered a contribution to deforestation in the country.

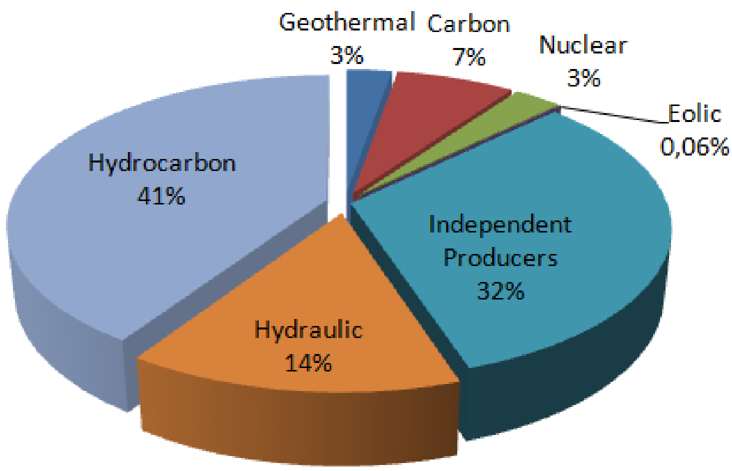

Figure 2: Electricity Generation in Mexico by Source (CFE, 2010)

Bagasse from the sugar cane industry provides 1.1% of the primary energy consumption, including 512MW installed electric capacity. Opportunities for biofuel production could increase considerably. The potential for electricity generation from biogas has been estimated on 3GW, but the current installed capacity still lies at 54MW and is growing at some 10MW per year since 2008 (SENER, 2011).

The production of bioethanol is likely to increase in the following years, as PEMEX will be buying up to 230 million litres anhydrous ethanol per year by 2017, which already would add up to some 0.1% of the current final energy consumption. Other energy crops include Jatropha, of which 8,113 ha have been sown between 2007 and 2011, mainly in Chiapas and Yucatán. According to the National Institute of Agriculture & Forestry (INIFAP) a total of 18,000ha could be used for biofuel crops (SENER, 2011).

Hydrocarbons are currently the main source of the world's electric energy and heat sources and also Mexico´s electricity by CFE sources are to 41% hydrocarbon based (CFE, 2010). The predominant use of hydrocarbons, which are an organic compound of hydrogen and carbon, is as combustible fuel source but hydrocarbons are also frequently used directly as heat when the hydrocarbons are being burnt. This heat is used to heat water, which is then circulated. A similar principle is used to create electric energy in power plants. Extracted hydrocarbons in a liquid form are referred to as petroleum or mineral oil, whereas hydrocarbons in a gaseous form are referred to as natural gas (Silberberg, 2004). Burning hydrocarbons is an exothermic chemical reaction, which produces steam, carbon dioxide and heat during combustion and therefore critically understood as "clean energy" as it contributes to greenhouse gas production.

Thermo-electrical energy generated by independent power producers (IPP) has a share of 32% of CFE´s electricity sources (CFE, 2010). The energy is obtained by the thermoelectric effect, a phenomena in which a temperature difference creates an electric potential.

Hydraulic energies make a share of 14% to the electricity supply, carbon contributes with 7%, geothermal with 3%, nuclear energy with 3% and only 0.06% is eolic (wind) energy (CFE, 2010). These last are produced in two windparks, one in Oaxaca and one in South Baja California, and appear as only real renewable energy source.
Of all installed effective capacity of energy generation 23,09% is produced by external IPP, which includes 22 plants in commercial operation from e.g. Iberdrola, Mitsubishi, EDF International, among others. To meet CFE´s goal to cover all energy needs of the country, the electricity generation capacity under the IPP scheme has increased during the last years.

1.2.2 ENERGY CAPACITY

The country generated 245 billion kilowatt-hours (Bkwh) of electric power in 2008. Conventional thermal generation represents the overwhelming majority of Mexico's electricity generation, though the mix from these sources is gradually shifting from oil products to natural gas (EIA, 2010).

The effective capacity of each energy source shows that most energy is generated by the use of the thermoelectric effect. Thermoelectric power plants in Mexico produce an effective capacity of 23.474,67MW, which stands for 46% of all capacity installed by September 2010 and independent producers of thermoelectric energy complete with a share of 23% and an effective capacity of 11.906,90MW to 69% of the share of all capacity to make the thermoelectric the most powerful energy source in Mexico (EIA, 2010).

Also hydroelectric plants contribute with 22%, an effective capacity of 11.174,90 MW, significantly to the energy generation in Mexico. The rest is generated by carbon electric (5%), nuclear electric (3%), geothermal electric (2%) processes and a very small amount of wind energy (eolic electric: 0,06%). All together a total capacity of 51.571,10 Megawatts was produced by CFE by September 2010 (CFE, 2010).

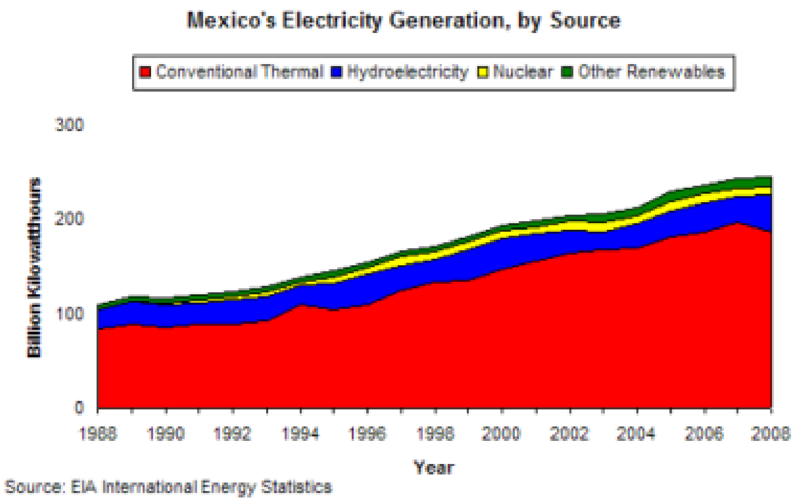

Figure 3: Mexico´s Electricity Generation Capacity by Source (EIA, 2010)

1.2.3 ENERGY DISTRIBUTION

The transition and distribution network is entirely controlled by CFE. The generated electricity is brought to the end users in SLP via a transmission net that considers voltage levels of 400, 230 y 161 kilovolts (kV) (CFE, 2010). Transformation is the process that allows using electrical substations changing the characteristics of electricity (voltage and current) to facilitate the transmission and distribution. It has grown in parallel to the development of the transmission and distribution, counting in September 2010 with three transmission substations with a potential of 1.610 ampere megavolt (AMV), ten distribution substations with a potential of 389 AMV and 8.666 distribution transformations with a potential of 368 AMV in San Luis Potosí City (INEGI, 2010). The distribution network is composed of sub-transmission lines with voltage levels of 138, 115, 85 and 69 kilovolts, as well as the distribution in levels of 34.5, 23, 13.8, 6.6, 4.16 and 2.4 kV and low voltage (CFE, 2010).

1.2.4 ENERGY CONSUMPTION

From 9.25 exajoule (EJ) primary energy produced in 2010 in Mexico, 93% came from fossil fuels. The net energy consumption in the same year was 8.15 EJ, which yields to a fairly low average of 75.2 gigajoule (GJ) per capita which, however, corresponds to an energy intensity of 4.96MJ/GDP (US$ PPP) and can be considered comparable to that of most European countries (SENER, 2010a).
The total consumption of electricity in Mexico in 2008 was 184 TWh (SENER, 2008).

	2007	%	2008	%	2009	%	2010
Users	741,534	2,8	762,48	3	785,418 City: 270,702		795,108
Sales (MWh)	5,049,512	-0,1	5,044,216	-8,1	4,637,305 City: 2,699,142		3,659,523
Products (thousands MX$)	5,425,046	20,2	6,520,438	-19,5	5,222,762 City: 2,985,482		
Price Medium (MX$/kWh)	1.0744	20,3	1.2927	-12,9	1.1262		
Consumption Medium (kWh/User)	576	-3,1	558	-10,6	499		

Table 1: Electricity Sales Statistics for SLP State, respectively City (CFE, 2010; INEGI, 2010)

The governmental secretary (SENER, 2010a) reports the national consumption shares as follows: the most part of electricity is used in the industry sector (59%), of which 38% apply to mid-sized industries and 21% to large industries. Households consume 26% of all energy used in Mexico, commercials 7%, the agricultural sector 4% as well as go 4% to services.

For the city of San Luis Potosí, 270,702 electric energy users were listed in 2009, of which 228,867 were domestic users, 37.039 users in the industry and service sector, 4.440 correspond to public lights, 240 to agricultural use and 62 for the pumping of water and wastewater (CFE, 2010).
Table 1 shows CFE´s Sales Statistics for the state of SLP in Mexico. Contradictory to the increase in the number of energy users observed, the sales in Megawatt hours have been declining from around 5 million MWh to around 3.6 million MWh from 2007 to 2010.
CFE determines the number of MWh sold in the city of SLP in 2009 on 2.985.482MWh, which makes around half of all MWh sold in the state in 2009. More than half of all electricity sold in the state was paid by the people from the city, around 3.000 million Mexican pesos (MX$) from around 5.000 million MX$ in 2009. The price medium was

rising and dropping around 1.000MX$ per kWh as the consumption medium in SLP state has been declining from around 570kWh per user in 2007 to 500kWh per user in 2009 (CFE, 2010).

In mostly all San Luis Potosí homes gas is used for cooking and heating water and even for some heating systems, cooling, drying and lighting. At the commercial sector, e.g. in hotels, restaurants, hospitals etc., and in the industry gas fulfils these purposes on even larger scale and is furthermore used in ovens with high temperature for treating and cutting of metals, glass and ceramics, in the ironing of clothes, in the purification of fats, pasteurisation, etc.

There are nine companies working in the gas sector listed in SLP: GlobalGas, Termogas, Gas Jebla, Sonigas, Gas Express, Gas Tomza, Gas Imperial, Energas and the biggest company Potogas has an operating plant with a capacity of 1.500,000 litres and advertises with sufficient transport infrastructure to supply directly from the refineries to their clients. The security of their facilities is said to be guaranteed with the latest technology and fully equipped 100 trucks with service to gas cylinders and 25 tank cars shall provide a quick and efficient service to costumer's demands (Potogas, 2011).

By the combination of carbon and hydrogen atoms, hydrocarbon gases are formed. The Liquefied Petroleum Gas (Gas LP) POTOGAS distributes, is composed of a mixture of approximately 70% butane and 30% propane, which has a higher calorific value available than other fuels (Potogas, 2011). The gas can be bought in gas cylinders of 10, 20, 30 or 45kgs, by a single delivery call when you ran out of gas or by contracting the company and gas will be filled programmed to ones individual consume. The monthly bill can be paid at any corner shop.
The trend of SLP´s households today changed to contracting natural gas companies like Gas Natural Mexico, when the gas is lead directly via tubes from the street access to ones household and ones individual consume is measured by a counter.

1.2.5 ENERGY REGULATION AND LEGISLATION

From 2004 to 2007, the tax burden of Pemex's revenues was 75% (and at some times more than 100% of the business profits), what led to a strong reduction of its equity capital. Even though it has doubled compared to the 90ths, the investment volume remains insufficient. Furthermore, currently about 80% of investments are financed by loans (bfai, 2007).

Among the main actors involved in Mexican energy policies are the Department of Energy (SENER), the Commission Energy Regulatory Commission (CRE), the National Saving Energy (CONAE), the Institute of Electrical Research (IIE), the Comisión Federal de Electricidad (CFE), the Ministry of Environment and Natural Resources (SEMARNAT), the Secretary of Social Development (SEDESOL), the Shared Risk Trust (FIRCO) and several other associations promoting the use of renewable energies (GTZ, 2005).

SENER is in charge of defining the energy policy of the country within the framework defined by the Mexican Constitution, ensuring the sufficient, competitive, high quality, economically viable and environmentally sustainable energy supply for the development of the country.

Since 1995 CRE is the main regulatory agency of the electricity and gas sector, grants permits for the generation of energy and approves under framework contracts the provision of energy and the methodologies to calculate the rates for private providers of energy.

CFE is monopolist for the Mexican electricity supply and controls the whole electricity network, including transmission and distribution.

CONAE promotes energy conservation and efficiency of energy and encourages the use of renewable energies. IIE´s function is the support of technological investigations in the electricity sector, including RE.

SEMARNAT establishes the national policies on environmental protection, and coordinates actions regarding Mexico's commitments made at the United Nations Framework Convention for Climate Change Climate (UNFCCC), along with the energy, transport, industry and agriculture sectors, among others.

SEDESOL promotes social development projects, including the use of RE, in particular the use of solid waste in landfills related to health issues.

FIRCO is a trust for specialist rural development programs, among which is included the use of RE in agricultural production activities. The most relevant associations for the encouragement of RE are: the National Solar Energy Association (ANES), the Mexican Wind Energy Association (AMDEE), the Mexican Network on Bioenergy and the Mexican Association of Energy Economics (AMEE) (GTZ, 2006).

The energy sector in Mexico is structured as shown in Figure 4. While the Ministry of Energy (SENER) coordinates the sector, it is divided into three main areas: hydrocarbons, electricity and government.

Firstly the hydrocarbon subsector's main entity is Petroleos Mexicanos (PEMEX), consisting of five subsidiaries: Pemex Exploration and Production (PEP), Pemex Refining (PR), Pemex Gas and Basic Petrochemicals (PGPB), Pemex Petrochemicals (PPQ) and Pemex International (PMI). The Mexican Petroleum Institute, a parastatal entity, gives technological support to Pemex and works closely with them.

In addition to these public entities, according to the Natural Gas Regulations published in 1995, a significant number of private companies are involved in the transport of natural gas, in its distribution (100% of this is done by private entities) and re-gasification of imported liquefied natural gas (World Energy Council, 2011).

The electricity subsector has as its main entity the Federal Electricity Commission (CFE, 2010) that generates 100% of the country´s electricity and also transports and distributes about 75% of the kilowatt hours (kWh) sold.

In the central government additionally exist three agencies that regulate and promote different aspects of the energy sector: CRE, CONAE, the National Nuclear Safety and Safeguards (CNSNS) and the National Institute for Nuclear Research (ININ), which conducts research and scientific and technological developments in the area of nuclear energy applications (World Energy Council, 2011).

The energy sector in Mexico has certain limitations in terms of private participation and foreign companies are allowed to operate in the country only with specific service contracts. According to amendments to the Law of Public Electricity Service in 1992, currently there are several private companies that generate electricity to CFE called Independent Power Producers (IPPs), what opens the possibility for private companies to import or export electricity. The Electric Power Research Institute provides technical support in the field of electricity to the two entities mentioned above as well as to Pemex and other public and private entities.

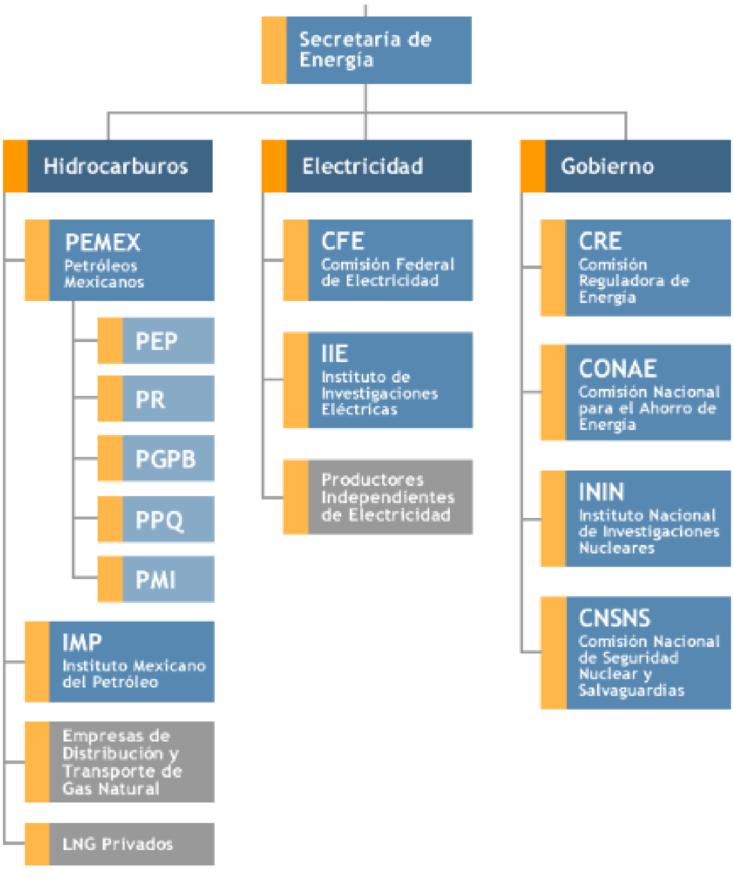

Figure 4: Structure of the Energy Sector in Mexico (World Energy Council, 2011)

The Execution and Production (E&P) activities in national territory as well as the refining activities from national hydrocarbons can only be executed by Pemex. Pemex E&P works through budget and through service and acquisition contracts.
Basic petrochemicals like ethane, pentane, propane and methane (when from aboriginal hydrocarbon resources etc.) are produced by Pemex exclusively. Secondary petrochemicals production is open to private investment. Both fuels, natural and LP gas, operate in a specific regime since 1995 which allows private investment in transportation, imports, distribution and storage.
Private investment is allowed to perform power production under the following modalities: Cogeneration, Self-supply, Independent Power Production, Small Production Exports and Imports for self-supply (SENER, 2010a).

Activities related to transmission, transformation and distribution, as well as power sales are exclusively developed by the state operator CFE.
The use of renewable sources of energy, such as wind, hydro, biomass, biogas, biofuels, etc. is allowed for private investors. There are specific interconnection contracts for the power projects from these sources of energy: Capacity recognition and energy bank (self-supply), net metering (small production of solar power), open access to transmission and distribution grids.
To exploit superficial and underground hydro resources it is required to have a usage or exploitation permit (SEMARNAT-CAN). It is also required to have a permit for the production, storage, transport, pipeline distribution and sales of biofuels (bioethanol, biodiesel, biomass and biogas). CRE is in charge of issuing the permits related to the activities from the power and natural gas sectors that are opened to private investments since 1995.

The Investment Promotion Office was created on February 1996 with the sole purpose of being a "customer service" window for private investors interested in the Mexican energy sector and to manage their opinions, projects and initiatives regarding the power and natural gas sectors. Through this office, the Ministry of Energy assists investors who have interest in private projects for the Mexican energy sector and provides assistance to private projects under development, participates in international and national forums to show and promote investment opportunities for private investors and provides information regarding the nation’s energy sector growth and the strategies used in the national energy policy (GTZ, 2006; SENER, 2010a).

The Public Electricity Service Act (LSPEE) regulating the provision of electricity in Mexico does not allow individuals the free purchase and sale of energy, but its generation, either for proper use or to supplement production processes by cogeneration, dependent on the permission from CRE. Individuals can also generate power for CFE as extern producers or small producers. From 1994 to 2005 CRE has approved 348 permissions for the generation of electricity, of which 317 are in operation (GTZ, 2006).

In December 2005 the Chamber of Deputies passed the initiative of the Law for the Use of Renewable Energy Sources (LAFRE), where a Program for the Development of Renewable Energies compatible with the existing law LSPEE was created. A goal for 2012 is that RE contributes by a minimum rate of 8% to the total electricity generation, excluding large-scale hydropower. In order to achieve this, priority will be given to feeding electricity from renewable energy sources into the grid. The law intends to set up a special financing mechanism, the Fondo Verde. Funds from the national budget would provide a production bonus, in addition to avoided costs, for mature renewable energy technologies (GTZ, 2006).

Mexico's Renewable Energy Development Law defines different rules, mechanisms and instruments to develop and expand renewable power generation (wind power, solar power, geothermal and hydropower). The law is meant to regulate the use of renewable energy resources and clean technology, establish specific targets for the portion of renewable energy sources in the energy mix in the short, medium and long terms. Regulatory measures and financial mechanisms to achieve these targets are also set out to incorporate renewable energy into the national electricity system (IEA, 2010).

Mexico ratified the Kyoto protocol but does not have any reduction commitments for the 2008 to 2012 period. In terms of national policies, a National Energy Strategy was set in 2007 which is valid for all the Mexican Republic. A set of goals were designed in order to achieve: 1) energy security, 2) productive and economic efficiency and 3) environmental sustainability. Achieving higher shares of RE for electricity generation and higher levels of electricity connection were also part of the objectives (SENER, 2012).

1.3 THE WASTE SITUATION

Since the beginning of life on our planet, closed or cyclical biological processes evolved, reusing all the materials that living things are made of and a variety of organisms were capable to metabolise and degrade deposited organic matter. In preindustrial times when the generated wastes had relatively limited volume and because of their predominantly organic composition and biodegradability, wastes have ended up being buried or dumped (Buenrostro, 2001a; Cortinas de Nava, 2001; Maldonado, 2006).

With the industrialisation, production processes accelerated, generating firstly larger volumes of waste and secondly stimulating an excessive consumption behaviour that, together with the packaging of products, also increased the amount of wastes generated. The latter has introduced new molecules to the environment, which living organisms do not know how to metabolise and therefore are not biodegradable or are slowly degradable, what makes them tend to accumulate where they are deposited (Cortinas de Nava, 2001).

In response to the growing waste generation and the changes in waste composition, the first Mexican sanitary landfill was built 1960 in Aguascalientes, which was followed by integral collection and disposal plans. Ongoing alarming environmental deterioration called the Nation´s attention in the 1970s and became formalised with the creation of the sub-secretary for Environment Improvement (SMA) in 1976 (Buenrostro, 2001b). In the 1980s the standardisation of MSW control began and the RS100 program launched in 1983, consisted of executive projects for sanitary landfills in cities with more than 100.000 inhabitants, where also manuals for the design of those and the collection routes were elaborated (Armijo de Vega, 2006).

The Secretariat of Environment, Natural Resources and Fishing (SEMARNAP) was created in 1994 and included in its structure the National Institute of Ecology (INE). In this framework, the INE assumed the responsibility of the development of municipal solid waste regulations standards and proclaimed the Official Mexican Standards (NOMs) in 1996, which establish the requirements for the selection of final disposal sites (Armijo de Vega, 2006). The SEMARNAP later transformed into the Secretariat of Environment and Natural Resources (SEMARNAT) and INE continued being responsible for the development of solid waste regulations.

Since the beginning of the last century Mexican municipalities have faced the responsibility to provide urban cleaning services and control the MSWs but the sole governmental responsibility and a lack of involvement of the society have brought Mexico behind the technical and administrative progress of waste management that other countries have achieved. The growing amount of MSW generated exceeded the required budget and capacity that governments can provide and furthermore resulted in weak efficiency in the waste management sector and clandestine, illegal waste disposal at open dumps (INE, 1999 in Armijo de Vega, 2006).

Like in many Latin American countries in process of development, there is no recycling system established and separation of wastes has become a segregated activity for marginalised social groups and has proliferated without the intervention of the Mexican government (Cortinas de Nava, 2001). Waste pickers in Mexico live in extreme poverty and obtain economic resources from the garbage collection and sales.

1.3.1 WASTE CLASSIFICATION

The terminology of solid waste (SW) differs from municipal solid waste (MSW), urban solid waste (USW), domicile solid waste (DSW), residential or domestic solid waste (RSW) household solid waste (HSW), hazardous waste (HHW) and brings confusion. It is often unclear if the term MSW refers to wastes identified by its type or simply because the municipality is responsible for its collection.

The Mexican environmental legislation defines MSW as "being generated by municipal activities that do not require special techniques for control, except for HHW and industrial wastes that do not derive from industrial processes itself" (Secretaría de Comercio y Fomento Industrial, 1985 in Buenrostro, 2011c).
The CDM Board for the UNFCCC (2011) defines municipal solid waste (MSW) as a "heterogeneous mix of different solid waste types, usually collected by municipalities or other local authorities" that includes household waste, garden/park waste and commercial/institutional waste.
The U.S. Environmental Protection Agency (EPA, 2006b) defines municipal solid waste as including "durable goods, non-durable goods, containers and packaging, food wastes and yard trimmings, and miscellaneous inorganic wastes." The term does not include all forms of solid waste, such as construction and demolition debris, industrial process wastes, and sewage sludge. The EIA differentiates between biogenic and non-biogenic waste in MSW.

Municipal solid waste (MSW) is defined as "all solid waste including HSW entering the city´s or municipality´s collection and treatment systems, excluding hazardous waste (HHW)" by Bernache-Perez (2001).
Buenrostro et al. (2001c) conceptualises MSW as "solid waste generated within the territorial limits of a municipality, independently of its source of generation" and suggested a hierarchical source classification of MSW that categorises into the three divisions: urban, industrial and rural, and into seven classes of sources: residential, commercial, institutional, construction/demolition, agricultural-animal husbandry, industrial and special. The latter may be hazardous wastes (HHW) from e.g. hospitals as well as they may occur in industrial residues.

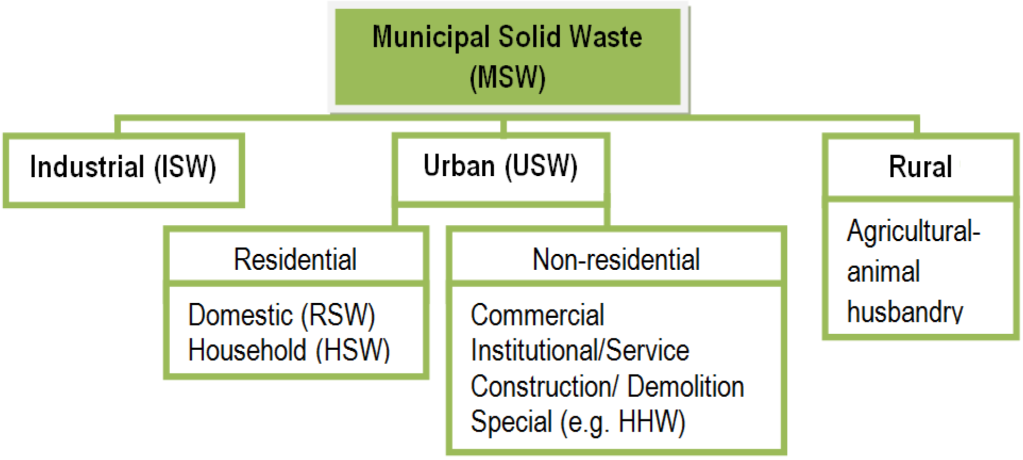

Figure 5: MSW Classification (Töpfer adapted from Buenrostro, 2001)

This paper uses the definition USW because the focus is on the metropolitan city of SLP, where the need of an improvement of the waste management became evident. Nevertheless, as urban, industrial as well as residential residues are managed per municipality, MSW can be understood as the wastes that are delivered to the local

disposal site and the terminology of MSW will therefore occur most times throughout this document.
In this study, residential sources are defined as household solid waste (HSW), which are "the wastes generated by the families activities at their homes"
For that reason, USW can be understood as a subdivision of MSW and are residential and non-residential wastes generated in the urban settlement of the city.

1.3.2 WASTE CHARACTERISATION

There is no real assessment of waste amounts and volumes on national level, mostly only truck loads are estimated. Nevertheless, several studies have been conducted about the composition of solid waste in some Mexican cities.

In the 1980s, the Center for Ecological Development (CECODES) carried out three studies, based on sample consumption and household solid waste (HSW) analysis, describing the composition and amount of HSW produced in the homes of 16 study areas of the Federal District (Restrepo & Phillips, 1982; Phillips et al., 1984; Restrepo et al., 1991; Bernache-Perez et al., 2001). Among them, Restrepo and Philipps (1982) analysed the daily processes of waste discharge and the advantages of reusing the different waste by-products in Mexico City. They described management practices and classified the types of residential and domestic solid wastes with high value. Trejo-Vázquez and Cespedes-Soto (1989) studied recycling practices in Mexico and recycled materials in urban areas. Their results coincide with the reports from Castillo-Berthier (2003), who identifies rubbish reusing and recycling in Mexico as an activity motivated by those in need to generate income rather than for environmental purposes.
Pioneer works by Buenrostro in the late 1990s (2001, 2003, 2006, 2008) focused on waste management in developing countries and showed the waste generation rates of residential sources in three different socioeconomic levels from the city of Morelia.
Two other studies were conducted in Hermosillo and Mexicali in the 1990s (Corral et al.,1995; Gaxiola, 1995; Encinas et al. 1996, Bernache-Perez et al., 2001; Ojeda-Benítez et al., 2003).

Bernache-Perez et al. (2001) and the Research Centre on Social Anthropology characterised solid wastes samples of HSW in the Guadalajara Metropolitan Zone in a statistical approach in 1997. They investigated the social and public efforts for MSW management in the country's second largest city and in 2001 the research followed up about the environmental impact of MSW management in Guadalajara (Bernache, 2003).
Armijo de Vega et al. (2003) proposed a garbage management system for Universities in North Mexico.

Maldonado´s (2006) staff established a USW minimisation programme in their public investigation centre in Merida, Yucatan where the personnel was requested to participate in waste separation with identified trash bins. In a three year study from 2000 to 2003 they determined the amount of organic waste and recycling material and showed that the amount of waste sent to the final disposal site could be reduced by two thirds with a proper recycling system (Maldonado, 2006). “The characterization in amount and composition of urban wastes is the first step needed for the successful implementation of an integral waste management system” and “fundamental for adequate decision making in the management strategy of urban solid waste” states Gomez et al. (2008). Her team characterised waste generated from households in Chihuahua City within three different socioeconomic levels in 2006.

1.3.3 WASTE GENERATION

Calculations by the SEMARNAT (2007) estimate a total generation of HSW of 0,9kg per day per inhabitant, whereas 0,4kg/d/person of wastes is produced in rural zones and 1,5kg/d/person in metropolitan zones.
Estimations assume that in the country about 95 tons of wastes a day are generated, which corresponds to about 34 million tons of waste per year. Around 53% of those wastes are organic biodegradable residues, 28% are considered to be wastes with high recycling potential like paper, glass, plastic, metal and textiles and 19% account to other types of materials. Nevertheless, currently fewer than 50% of the potential recyclable materials are recovered (SEMARNAT, 2007).

The United Nations Organisation (UNEP, 2009) produced indexes with keys and descriptions for all economic activities. This international standard industrial classification (ISIC) bases on the rationale of classifying economic levels of specificity. The existing Mexican official classification of Activities and Products (CMAP) (INEGI, 2010) in fact bases on the ISIC.

Buenrostro et al. (2001) tested this approach at state and municipal level to study the composition of SW in Morelia, Michoacan in 1999. In order to determine the type of SW generated, the description of the economic activity provided by CMAP was compared with the listings included in the Mexican environmental legislation (SEDESOL, INE, 1993; SEMARNAP, 1995 in Buenrostro et al, 2001), which describes the characteristics of SW according to the generating activity (Buenrostro et al., 2001). The created database based on information from the economic census of 1991, containing demographic and socioeconomic parameters. The gathered data was managed in a Relational Database Management System (RDBMS) where the variables are the number of households per municipality and the number of inhabitants per municipality. He assumed that the results could be extrapolated to similar areas.

His research team located a total of 92.065 non-residential and 781.632 residential sources for a quantitative description of the MSW sources. In the city of Morelia 145.738

sources were taken, which accounts for a daily generation of 364,5 tons of MSW. It was shown that at state level 87.5% and city level 84.6% of the MSW were residential sources, 6.1%, respectively 7.1%, belonged to commercial sources and the rest was industrial, markets, service and special waste sources (Buenrostro et al., 2001).

The methodology used for most of the studies in Mexican metropolitan areas was developed by Rathje (Rathje & Mc Carthy, 1977) and bases on the "direct sampling of solid waste from specific sources, a labour intensive manual process of sorting, classifying and weighting all items in each sampling units, and a detailed recording of the data" explains Bernache-Perez (2001).

In a study from 2007 in Chihuahua, 560 samples of solid waste were collected during one week from 80 households, sorted and classified into 15 weighted fractions. The average waste generation in Chihuahua was calculated at 0,676kg per capita in April 2006 with a dominant fraction of 48% organic wastes among 16% paper and 12% plastic (Gomez et al., 2008). In Chihuahua 60% of the total USW was collected by the municipal service and 40% by private waste collection services. The average waste generation was around 1000 tons per day, 60% of which corresponds to waste generation in households (Garay, 2006). These results are comparable to the value of 56% share of HSW from 300 samples reported by Bernache (2003) for Guadalajara.

The average per capita daily HSW generation rate was 508g in Guadalajara and consisted to most parts (53%) of decomposable waste. The average daily generation of MSW was 3119,2 metric tons [Mg] entering the local disposal sites and are equivalent to 0,5- 0,86 to 0,96kg/person/day for Guadalajara. HSW represented 55,9% of the MSW and the main difference was a lower proportion of organic material in MSW (16,5%). Only 2,2% of the total MSW was sorted for recycling, which was mainly packaging material. With respect to the daily per capita generation rate of HSW, it can be suggested that the rate estimated for Guadalajara of 508g in 1997 (Bernache-Perez, 2001) can be regarded as similar to HSW generation rates for other Mexican cities like e.g. SLP.

Table 2 provides a direct line-up comparison of the waste generation data from Mexican cities that could be obtained by several researchers in the past years.

City	Year	Samples	Per capita	MSW	HSW	Organic Share	Source
Mexico	1988		0,566kg/d	58.619t/d	47.482t/d		SEDUE, 1998
Mexico	1992		0,613kg/d 0,261kg/d	70.754t/d 21.967.525t	58.962t/d		SEDUE, 1998, SEDESOL1999
Mexico	1998		0,318kg/d	30.550.504t			SEDESOL,1999
Mexico	2000		0,718kg/d	92.838t/d	77.365t/d		SEDUE, 1998
Mexico	1992-1998		0,917kg/d				Buenrostro,2003
Mexico	2007		0,9kg/d	95.000t/d 35.000t/y			SEMARNAT, 2007
SLP	2009			929t/d			INEGI, 2010
Guadalajara	1997		0,508kg/d HSW	3119,2Mg	1743t/y 55,9%	52,9%	Bernache, 2001
Guadalajara	2001	300 HS	0,911kg/d MSW 508g/d HSW	3119Mg/d	55,9%	53,8%	Bernache, 2003
Chihuahua	2006	560	0,676kg/d	1000t/d	60%	48%	Gomez, 2008
DF	1991					53,4%	Restrepo, 1991
Cuitzeo Basin, Michoacan	2001	290 (426kg)	0,4kg/d	425,6kg		62,42%	Buenrostro, 2001, 2003, 2007
Michoacan state	1998	892.317		2161,7t/d	87,5%		Buenrostro, 2001
Morelia	1996-1998	117/32 697kg	0,609kg/d MSW 0,629kg/d HSW	367,2t/d(wet) 304t/d USW	321t/d(wet) 307.034kg/d 2,49kg/d/HS 87% of USW		Buenrostro, 2001b
Morelia	1998	145.738	0,63kg/d	364,5t/d	84,6%		Buenrostro, 2001
Morelia	2004	303 HS	0,7kg/d	700t/d	3947,2kg 442t/d	2500kg/y, 7kg/d	Buenrostro, 2003, 2008
Merida	2000-2003			77.280kg/y 1646m³ V 6440 kg/m		48%	Maldonado, 2006
Mexicali	1995					46,9%	Gaxiola, 1995
Mexicali	2001	970 (7215kg)		7215,4kg		27,74%	Buenrostro, 2001, 2007
Culiacán	1995					54,6%	Gaxiola, 1995
Hermosillo	1995					41,32%	Corral,1995

Table 2: Waste Generation Comparison between Mexican Cities

1.3.4 WASTE COLLECTION

The urban cleaning systems in Mexico consist of six elements: 1) storage in the generating source, 2) manual and mechanical sweeping, 3) garbage collection, 4) transportation and transference, 5) treatment and 6) final disposal.

In public places like schools, shopping malls, hospitals where large amounts of garbage is generated, the storage of the disposed wastes was hardly kept in mind and at best temporary waste storage facilities were introduced. The lack of infrastructure provoked the establishment of local dumps at the area.

The shared task of sweeping the streets and sidewalks of Mexican towns between the government and the citizens has decreased significantly and has in larger cities even become inexistent. The sweeping service is to big parts done manually, only in larger Mexican cities and public places mechanical equipment is used (SEDESOL, 2002 in Armijo de Vega, 2006).

Since the main goal of the collection service of MSW is achieving public health, it was operating under principles of highest efficiency and lowest costs (INE, 1999; SEDESOL, 2002 in Armijo de Vega, 2006). By 2007 the collection service of urban residential solid and special wastes covered 87% (SEMARNAT, 2007).

Only around 27% of Mexican cities count with efficient collection routes, where the most commonly used collection equipment is compacting trucks with a capacity of 10-15m^3 that can collect 6-8 tons on one way. This poor infrastructure results in a waste concentration in rural areas and distant neighbourhoods (GTZ, 2006).

In Mexico there are two types of transportation services. The collection vehicle realises the collection from the residential deposit all the way until the treatment or final disposal site or the MSWs are transported to transference sites for subsequent transfer in order to diminish the collection operation time and costs. In Mexican metropolitan areas more than 75% of the collected wastes go to transfer stations (Armijo de Vega, 2006).

1.3.5 WASTE DISPOSAL

Waste treatment options like incineration, utilisation of sub-products, recycling and composting did unfortunately not find much success in Mexico. For reasons of market competition in this field, most treatment plants had to stop operating and this is why most of Mexican garbage is not treated but ends directly at the disposal site (Armijo de Vega, 2006). Here it is important to consider that most of Mexican disposal sites are open dumps and few are the ones that comply with the national requirements of the NOMs.

The strategy for most municipalities is burying the wastes, as it is considered the simplest and cheapest disposal way and most sites do not offer the necessary design and construction quality that are central for a sanitary landfill (Castillo, 1983; Bernache, 2003). Most landfill locations were decided rather because authorities could buy the close, cheap, available land than based on geological, biological and hydrological considerations (Bernache, 2003; Maldonado, 2006).
From the amount of collected wastes, 64% were deposited in controlled sanitary landfills and the missing 36% were inadequately dumped at open disposal sites (SEMARNAT, 2007). Additionally to health and environmental risks of these disposal sites need to be seen the attraction of animals, odour, social conflicts and the deterioration of the landscape and urban image.

Mexico counts with 88 sanitary landfills and 21 controlled disposal sites (SEMARNAT, 2007). In 2007 71 Mexican sanitary landfills have been registered for the Clean Development Mechanism (CDM) under the UNFCCC (2007). It is stated that gas venting tubes are often clogged, leachate capture systems often overflow and there are hardly pollution control devices.
No formal recycling programs have been implemented in Mexico so far but a significant amount of wastes is recovered by scavengers.


Figure 6: Pepenadores at Peñasco (Töpfer, 2012)

Waste pickers on Mexican dumpsites are called "pepenadores". The word originates from náhuatl language "pepena", which means in Spanish "escoger, recoger" and in English "recollect". Scavenging is a family business, mostly the father and the kids search for materials on the field and bring them in large sacks to the camp, where the mother would classify the residues by material composition, make final separations and place them in piles and containers, where intermediate salesmen come to buy the recyclable resources on the spot. Outside the landfill material prices would be better, but the pepenadores mostly do not have transport possibilities.
For the pepenadores, waste by-product commercialisation pays off only when large volumes are obtained. Current prices on glass are at 0.027 US$/kg and the most profitable are PET bottles, that are around 0.089 US$ cents per kilo (Maldonado, 2006).

Pepenadores in Mexico´s Federal District have been reported to recover and recycle between 6 and 10% of the overall MSW volume (Bartone, 1991; Sancho y Cervera & Rosiles, 1999 in Buenrostro, 2001a). In La Micaelita, Guadalajara a 12,4% material recovery was reported (Bernache-Perez et al., 2001). Other studies (Bernache, 2003) indicate that only 2% of the total MSW is separated and sold to commercial and industrial agents that recycle it. The most important agents are the pepenadores in material recovery activities.

Bernache-Perez et al. (2001) found large differences among sites relating to their scale, intensity and scope of separation procedures and suggested these due to “differences in policies and regulations imposed by the sites’ authorities”. For example, at a disposal site with numerous groups of scavengers also lower commercial value wastes are collected, what results in a higher amount of materials separated. Whereas the small amount of recycling made at e.g. Los Belenes Transfer Station in Guadalajara (Bernache-Perez et al., 2001) could be seen as result of the few pepenadores that are allowed to work there.

1.3.6 WASTE REGULATION AND LEGISLATION

Necessary policies for the sustainable management of municipal waste in developing countries, especially in Mexico, have not yet been put into practice, although they exist in environmental regulations and government recommendations (SEMARNAP, 1999; SEMARNAT, 2010). According to Article 115 of the Mexican Constitution, section III, paragraph C, the municipality is responsible for the "cleaning, collection, transfer, treatment and final disposal of wastes." Practically in every state and municipality there are special regulations to this respect.

With the enforcement of the General Law on Prevention and Integrated Waste Management in January 2004 it was established that the authorities of the three divisions of the Mexican government deliver an information system on integrated waste management that includes relative information about the local situation, an inventory of the generated wastes and the available infrastructure.
Mexico counts with a general legal framework on prevention and integrated waste management, which is supported by the Political Constitution of the United Mexican States. This framework includes the General Law for Ecological Balance and Environmental Protection (LGEEPA) from 1988, the General Law for the Prevention and Integrated Waste Management (LGPGIR), the corresponding regulations, as well as the Official Mexican Standards (NOMs) that apply throughout the country.

Wastes are controlled by the Official Mexican Norm NOM-083-SEMARNAT-2003, that was established in 2003 and is dedicated to “environmental protection specifications for the selection at the site, design, construction, operation, monitoring, closure and complementary works of a final disposal site for municipal solid waste and special treatment waste” (PROFEPA, 2004 in SEMARNAT and GTZ, 2005). The norm is mandatory for all private and public entities responsible for their waste disposal. In Mexico the handling and disposal of MSW is a major environmental challenge since it is estimated that only 35% of the municipal landfills under supervision comply with the environmental standards, mainly the NOM-083.

Industrial wastes are controlled by the Norm NOM-052-SEMARNAT-1993, which establishes the "characteristics of hazardous waste, the list of them and the limits to when a waste is hazardous by its toxicity to the environment" (PROFEPA, 2004 in SEMARNAT and GTZ, 2005). Hazardous wastes are classified following the characteristics of corrodibility, reactivity, explosiveness, toxicity, flammability and the biological infectious risk, which are established in the NOM-052.

Controlling bodies are the Federal Attorney for Environmental Protection (PROFEPA) and the National Institute of Ecology (INE), which are integrated into the Secretary of the Environment and Natural Resources (SEMARNAT) and the Secretary of Ecology and Environmental Management (SEGAM).
The legal framework is in development of the creation of new state laws or modifications on existing environmental laws and the preparation of the relevant municipal regulations (SEMARNAT, 2007).

Moreover, the national legislation applies a series of international treaties, which the Mexican Government has signed, among which are the Basel Convention on transboundary movements of hazardous wastes and their disposal, the Stockholm Convention on persistent organic pollutants, the Kyoto Protocol on climate change and the Montreal Protocol on substances that deplete the ozone layer, of which a series of obligations related directly or indirectly with waste management arise (SEMARNAT, 2007).

1.4 DISCUSSION

Mexico is currently facing major energy challenges: the country is the only major oil producer, where in recent years a significant decline of oil reserves was recorded. The necessary investments in the energy sector are confronted with state budget that is heavily dependent on the oil revenues as well as constitutional provisions prohibiting any privatisation in this sector. Cooperation with foreign companies is difficult, which is why Mexico's current energy deficit shall be offset by the diversification of energy sources (bfai, 2007).

The lack of investment in the energy sector is manifested in various ways: Natural gas, gas LP, gasoline and petrochemical products have to be imported, even though Mexico is a natural gas producer. Regardless of the amount of Mexico´s oil reserves, their refining capacity is insufficient and today more than 40% have to be imported, mostly from the USA, to cover the high gasoline consume - tendency rising (bfai, 2007). At the same time the monopolist Pemex sells the imported gasoline at a loss to the end users and subsidises the price of gasoline.

In accordance with the Electricity Sector Outlook (SENER, 2009), the decreasing trend in the participation of renewable energies in the energy matrix of public services will continue during the coming years. However, taken into account the self-supply and cogeneration projects, the participation of renewable energies will increase in the next years, allowing the fulfillment of the goal established in the Sectorial Program of Energy 2007-2012 of reaching 26% of the installed capacity (SENER, 2009).

Infrastructure deficiencies cause power shortages and the supply does not cover the demand. This situation is mainly due to strong fiscal and legal restrictions for public and private companies in the energy sector, a barrier for any investment in e.g. de development of renewable energy sources.

The ongoing privatisation of state-owned enterprises will increase the demand for site-assessment and remediation services and will provide additional capital that can be used to invest in environmental projects (Lynch, 2002).

Regarding the waste situation, the first necessary step is a classification and characterisation of MSW, USW and HSW. It was shown that waste generation amounts for Mexican cities show some similarities; waste generation rates per capita differ from rural to urban areas and are mostly overestimated. The percentage of decomposable wastes in HSW in large urban areas in Mexico has not significantly changed over the last decades. This difference probably is still due to the common practice in Mexico of buying mostly unprocessed food from the markets to be prepared and cooked at home like fresh vegetables and meat what results in a higher share of organic wastes. Differently to industrial countries where foods are mostly bought in supermarkets, processed and ready to eat, leading to a lower representation of food wastes but higher percentage of packaging materials in HSW.

Some waste characterisation studies provide information on waste generation amount, volumes and composition for Mexican cities that were presented in table 2. It becomes obvious that the results are not very comparable with each other, as they were achieved from different years, by different methods, differ in sample size, sample origins and treatment, use different terminology and definitions like USW, MSW or HSW and finally were presented in different units.

As reliable waste classification studies in Mexico are rare and there is no unified waste system or a real waste management plan, the government and statistical institutions could not provide recent data. Given this difficulty in obtaining precise data, it was not possible to arrive to an exact presentation of the amount of wastes generated in Mexico.

Nevertheless, the table and descriptions gives an overview on waste generation figures on national level and for several cities that are comparable to SLP.

Once there is data and information available on consumption, generation, amount, volume, composition, transportation, disposal, separation and treatment of wastes as well as problems and challenges in current policies and regulations from a social, economic and environmental point of view are taken into account, there can be an initiative towards a properly designed waste management. To become sustainable, the waste management needs to be improved as final disposal sites in Mexico often still lack basic technology and infrastructure to ensure an adequate and safe disposal, also of hazardous wastes (Bernache-Perez et al., 2001).

Article 115 of the political constitution of the United Mexican States provides that the municipal authorities have to provide cleaning services and are responsible for the waste management. As consequence from a lack of public involvement and environmental education, the growing waste generation exceeded the waste management capacities and made Mexico lag behind the technical and administrative progress of other countries. The short duration of local governments, which at best are in charge for a period of three years, furthermore interrupts a continuously implication of policies and projects, as municipal regulations on energy and waste issues depend strongly on national laws and policies.

1.5 CONCLUSION

Mexico is an OECD country and holds considerably large oil and gas reserves. PEMEX, the national monopolist petrol company also uses big amounts of LP gas. Despite being a main producer, Mexico needs to import around 40% of gas and oil from the USA, which is sold highly subsidised to the end-user (EIA, 2010). Electricity sources in Mexico are mainly hydroelectric, hydraulic, hydrocarbons and thermoelectric. Less than 1% of the Mexican electricity supply is delivered by renewable energy sources (CFE, 2010). Popular energy source for cooking is still biomass.

The SENER is in charge of defining the energy policy of the country within the framework defined by the Constitution. Since 1995 CRE is the main regulatory agency of the electricity and gas sector. The energy sector in Mexico has certain limitations in terms of private participation and foreign companies are allowed to operate in the country only through specific service contracts. As required by the Constitution, the electricity sector is federally owned, with CFE essentially controlling the whole sector (EIA, 2010) and holds a monopoly position also for the transition and distribution network.

Mexico has no existent emission policies and environmental policies are established at municipal level. There is no GHG monitoring, no existent CC action plan. In 2005 a national RE energy law LAFRE came into force, that has the goal to achieve 8% share of

RE to the total electricity generation in 2012, excluding large scale hydropower. This is party supported by the national financial mechanism, the fondo verde (EIA, 2010).
Mexico ratified and signed Kyoto, but has not reduction goals for the period 2008-2012.

Waste management in Mexico is organised for municipalities, which means every state and city has different approaches on how the wastes will be recollected and treated, there is no uniform system. Generally, Mexican waste management covers around 90% of Mexican cities. The generation of HSW was calculated on 0,9kg per day per inhabitant, where 53% of the HSW are organic wastes. On national level, Mexico produces about 95 tons of wastes a day, which corresponds to about 34 million tons of waste per year (SEMARNAT, 2007). Wastes are mostly picked up at the residential generation source by recollection trucks and brought to transfer stations before they are transported to the final disposal sites.

Wastes are controlled by Official Mexican Norms that were established by the SEMARNAT. Very few sanitary landfills comply with the NOM-083 and open dumpsites or clandestine waste disposals are not uncommon as furthermore the collection service only covers around 90% in the cities.
The management of MSW represents a serious problem for municipalities and government entities in Mexico, because there is no widespread interest from the side of the population regarding its adequate management. Generally, waste management in Mexico is reduced to collection and final disposal, even though in some cities treatment and recovery has been introduced.
National population growth, accelerated trend to urbanisation (Buenrostro et al., 2001; SEMARNAT, 2007) results in growing waste generation and shortages of economic resources for the collection, transportation and storage of MSW and for the construction of suitable final waste disposal sites like sanitary landfills (Castillo-Berthier, 2003), enhance the problem. Experiences in Mexico have shown that most landfills were constructed at a site because the land was available rather than because the soil was in the condition of absorbing big waste amounts, causing quick saturation of those landfills (Maldonado, 2006).

Chapter 1 served as theoretical analysis that offers a well investigated background overview on the current situation of the energy and waste sector in Mexico and will be referred to in the following chapter that focuses on the waste management in the city of San Luis Potosí.

CHAPTER 2: CHARACTERISATION OF THE WASTE MANAGEMENT IN SLP, MEXICO

2.1 INTRODUCTION

Like other cities in Mexico, San Luis Potosí (SLP) faces serious environmental and administrative challenges with respect to solid waste management. The public sanitation system was established with weak planning and a sustainable and efficient waste management system is still in process. Population growth and rapid industrialisation, followed by changes in consumption patterns, has resulted in an increased generation of urban wastes.
The municipality of SLP seeks to administer the local sanitary landfills according to the Mexican legislation, but lack financial means and the technical and human infrastructure. The collection service depends strongly on personnel that hardly count with technical training and the only separation of resources is accomplished by numerous pepenadores.

Given that organic fractions of domestic wastes from the cities are valuable energy sources, its potential remains insufficiently used and studied. Uncontrolled waste disposal can cause severe problems for health and environment. Improper waste management is contributing to climate change, water and soil contamination and local air pollution instead of providing energy. Recycling organic waste and using biomass to create energy also requires the establishment of efficient environmental policies and programs on sustainable management of natural resources. On local level, ecologically sustainable solutions for a central challenge of environment and climate conservation and the participation of international organisations as well as binding framework politics are needed.

There have been some studies about waste characterisation and classification in Mexican cities in the last years. Some of these results, which were presented in chapter 1, are comparable to the situation in SLP. For the city of San Luis Potosí there have not been undertaken any investigations on waste management until now. Since the local waste management has been initiated recently and for other reasons that will be shown in this chapter, there is little data available. For the best of my knowledge, this document is one of the first descriptions of SLP´s waste management and its problems and challenges. In this chapter the current situation of SLP´s management system will be analysed and the environmental, technical, administrative, economic and social goals will be presented.

2.2 METHODOLOGY

As this study is mainly a socio-economic survey, most of the information was received by participant observations and intensive literature and data research. I was engaged as non-permanent citizen of SLP for 15 month in the everyday life of the city´s activities, participating in the generation of household waste, observing the collection and transportation, getting to know the habits and relation of the citizens to waste and talking to people involved at community, institutional and political level.

It was possible to obtain concrete statistical data at hand from the national statistics centre INEGI and inside information by participation and observation and collecting practical experiences and interviewing experts and participants.

The given study resembles Participatory Action Research (PAR), which “is a recognised form of experimental research that focuses on the effects of the researcher's direct actions of practice within a participatory community with the goal of improving the performance quality of the community or an area of concern” (Hult & Lennung, 1980).

Furthermore I conducted qualitative open interviews with representatives of several institutions, locals, researchers as well as experts and employees from both local and international organisations like the GIZ and SEMARNAT, the Municipality of SLP, Department of Ecology and Urban Sanitation. Visiting the local dumpsite Peñasco with the Municipality of SLP delivered inside information about the waste disposal and an overview about SLP´s waste management and its possibilities. I obtained information from Red Ambiental, the company responsible for the urban waste collection in SLP and ENERGREEN, the company in charge of the exploitation of biogas at the sanitary landfill of SLP.

The scientific research was based on the Internet; as well the library of both the UASLP and CUAS, ITT were used. Access to historical dates and numbers of the statistical archive was provided by the national statistic centre INEGI.

2.3. DESCRIPTION OF THE STUDY AREA

San Luis Potosí, the capital of the same called state in the north of Mexico, is located at the coordinates: 22°08′59″N latitude and 100°58′30″E longitude. Neighbouring states Nuevo León, Tamaulipas, Veracruz, Hidalgo, Queretaro, Guadalajara and Zacatecas make San Luis Potosí (SLP) a city well located on halfway the country´s capital Mexico City and the border to the USA. The mountain range of the Sierra Madre Oriental marches through the north and the south of the state, which divides SLP into one big part to the northern cold Altiplano and, in contrast, to the more humid lowland the Huasteca.

Figure 7: SLP Map (INEGI, 2010)

At an altitude of 1860m, the city of SLP is marked by semiarid climate of 17,3°C medium around the year and an annual medium precipitation of 387,8mm (INEGI, 2010), of which the heavy rain falls in the few month of July, August and September and during the rest of the year typical dry desert climate can be experienced.

San Luis Potosí´s metropolitan area, including the suburb Soledad de Graciano Sanchez, inhabits around 1 million inhabitants; the mere city centre with an area of around 385 km^2 is said to contain 730,950 inhabitants, what makes SLP the tenth biggest city in Mexico (INEGI, 2010). Currently, the municipality of SLP counts with 772.604 inhabitants (INEGI Census, 2010).

The population´s GDP per capita in 2010 was estimated at 9.000,00 US$, mainly derived by commercial and industrial activities (INEGI, 2010).
The Human Development Index (HDI) for the State SLP with a score of 0,8165 (CIA, 2010) is considered high. Today the city is one of the main industrial centres in central Mexico with a successful manufacturing industry in automobiles and construction. Influences from the agricultural sector and the mining industry from the close surroundings have to be noticed in the overall image.

In 2009, a total of 257.841 motorised vehicles were registered circling around San Luis Potosí (INEGI, 2010). This enormous traffic is regulated at two crosspoints, three underpasses and 26 highways leading the traffic away from the main roads. What once ran through SLP as river has been modified to one of the main roads, the Carreterra of the Rio Santiago, but turns back into a rapid stream when heavy rainfalls in summer convert the city´s streets into runnels, due to improperly planned drainage systems.
The public transport system is run by 2.145 buses transporting passengers registered by INEGI in 2009, passing frequently in 32 routes at all colonies of the city. San Luis Potosí counts with several green spaces and parks, of which the largest is Parque Tangamanga I with 411ha, Parque Tangamanga II and Parque Morales at the University Zone, among others. Even in wealthier colonies like "Las Lomas" the buildings and houses are mostly bad constructed, as to say badly isolated and with little efficient energy services.

Situated in the desert, SLP´s dry conditions cause enormous water consumption, whether for watering the exhausted soil and plants or to meet life activities demand. There are 5.298 points with permission to drain wastewater, most of them urban public, releasing a total volume of 138.39 million m^3 wastewater in 2010 (CNA in INEGI, 2010).
SLP´s emissions are stated to be below the official Mexican norm (MXN-AA-1993) on air pollutants, but still, particulars expelled, especially from the industrial activities, contribute to GHG emissions. In 2010, only 3.252 vehicles in SLP were verified on particulars emitted to the atmosphere (INEGI, 2010).

In the following part more detailed information about the local waste management in SLP will be explained

2.3 WASTE MANAGEMENT IN SLP

Waste management in Mexico is organised for municipalities, every state operates differently. The distribution in Urban Recollection Service from Red Ambiental and the voluntary recollection service that work independently, is unique for SLP. There were initiatives to include the voluntary collectors to the urban service system but did not result successful. The company Red Ambiental was contracted by the municipality in 2009 and will operate for 15 years in SLP.
According to INEGI (2010) the volume of waste collected in the city of SLP in 2009 was 302.000 tons. Recent estimates by authorities from the municipality state a number of approx. 900 tons of waste generated in the city per day which would amount to a total of 328.500 tons for 2012 (Govea, 2012 pers. com.)
These wastes are brought to the local landfill Peñasco that operates since 1995 on a size of 14ha and where 929 tons of residues per day were delivered in 2009, according to INEGI (2010). Peñasco has recently been sanitised and today only two cells receive waste from the municipality. There is a project planned for the exploitation of landfill gas and the landfill is adjusted with gas sockets.
Around 800 pepenadores work at the landfill separating high value resources like plastic, paper, aluminium and glass to sell these. There is no official recycling system and organic wastes are not energetically used yet.

2.3.1 WASTE GENERATION

Figure 8: HSW samples in SLP (Töpfer, 2011)

The most recent number of waste generated in the city of SLP delivered by INEGI (2010) stated 929 tons of wastes per day that were brought to the local disposal site and a volume of urban waste collected in 2009 of 320.000 tons.
This leaves room for interpretation whether 302.000 tons are USW out of 339.085 tons MSW in SLP.
The Department of Ecology and Urban Sanitation of the municipality SLP (Govea Tello and Cervantes, 2012 pers. com.) provide an estimated number of 900 tons of wastes per day, in peak time around December up to 1100 tons per day, which arrive at the municipal disposal site. These wastes can be classified as MSW, generated by the municipality SLP and Santa Maria del Río.

Considering these 900 tons of waste generated per day (Govea Tello, 2012 pers. com.) this would amount to a total of 328.500 tons of MSW for 2012.
The average residential solid waste (RSW) generation in fact is commonly calculated at 1kg/person/day. Taking into account the current number of the SLP municipal population of 772.604 inhabitants (INEGI, 2010) this would amount to a total of 772 tons of RSW per day and 281.780 tons of RSW in a year. Currently there are 199.446 households registered in SLP (INEGI, 2010).

The next information that could be obtained is a reported accumulation of more than 10 million tons of waste at the local dumpsite Peñasco during 18 years (Red Ambiental, 2011). Calculating 10.000.000 tons divided for 365 days would mean a generation of 555.555 tons of MSW per year.

2.3.2 WASTE COLLECTION

In SLP, the system is distributed into Urban Recollection Service (Servico Urbano de Recollecion), performed by the company Red Ambiental contracted by the municipality of SLP and the Voluntary Service of Waste Recollection (Servico Voluntario de Caretoneros) who work independently.

Formerly there were big trash containers in every three blocks of the city where the people had to walk to and deposit their waste bags. These containers were recollected every week by trucks and changed by empty ones.

In 2007 the municipality installed 3000 public trash bins ("papeleras" from the company Plastic Omnium) in the city, mainly for the purpose to keep the streets clean and give the habitants a possibility where to throw their garbage while being on the streets. These trash bins then were a gladly seen alternative to throw the household waste bags or to put the bags below the bins as these obviously filled very quickly. Consequently, the municipality decided to better pass with the garbage trucks at the houses and pick up the waste bags from in front of the doors.

Figure 9: A Waste Collection truck from RedAmbiental (La Razon, 2012)

The streets and public places today are swept and kept clean by 500 workers contracted by the municipality (Govea Tello and Cervantes, 2012 pers. com.). Furthermore high value resources like plastic, paper, aluminium, glass are picked up by scavengers from the waste bags or waste bins in the streets. Organic wastes are not used.

Like many cities in Mexico, SLP lacked good service of garbage collection. Broken trucks, lack of personnel and planning of service as well as the lack of resources from the council constantly kept the garbage in the streets, causing serious health problems for the public, environmental degradation as well as innumerable complaints from the population.

In 1998, with the intention of providing its services to a growing industry sector in Monterrey, RED RECOLLECTOR was born. Since 2009 RED AMBIENTAL is responsible for the collection of urban wastes and the landfill of the city of SLP in a 15-year contract with the municipality. By 2000 VIGUE was integrated, complementing the chain by counting with an own sanitary landfill that complies with the official Mexican standard NOM-083 and all the respective authorisations. The company counts with the Clean Industry certification, complies with the Standard ISO9000 and furthermore receives the Global Environment Fund (Red Ambiental, 2011).

When from 2009 on the municipal administration made the decision to concession an integral service from the company Red Ambiental, they were looking for a definite solution to the problem of the recollection of garbage that for years affected the community. Based on the route designed by engineers and according to the characteristics of the city, Red Ambiental made themselves responsible for the waste collection service in SLP for the next 15 years. Today, after 14 years of experience in this service, they are the biggest company in its field nationwide, with presence in 10 cities across the country, with over 300 trucks in operation and 3500 active clients and moving more than 7000 tons of waste per day in Mexico (Red Ambiental, 2011).

The service previously provided by the municipality of SLP with 53 trucks is now done with 34 units, which also represents a considerable saving for the council. "These decisions are fundamental for the development of a city. [...] The idea is not to take work from anyone but to find these win-win schemes in which many problems can be solved", said Jorge Lozano Armengol, Mayor of SLP 2009 (Red Ambiental, 2011) referring to the voluntary waste collectors that still operate in the city.

There are 39 motorised vehicles for garbage collection registered in the city, of which three are private unions: Francisco Villa and two without name. The recollection trucks in SLP have 148 routes, without counting the private trucks and the voluntary pick-ups. There were initiatives to include the voluntary collectors to the urban service system, but it did not find much reception, as these people like working independently and being their own bosses (Cervantes, 2012 pers. com.).

Among several voluntary recollection unions, there are registered Frente Recolector Urbano, Recolectores Libres, Federación de Prestadores de Servicios Únicos y Similares, Confederación de Trabajadores de Mantenimiento Limpia, Unión de Servidores de Limpieza Pública, Prestadores de Servicios, Unión Independiente, as well as numerous family businesses that collect the trash bags from the streets and drive them in their pick-ups to the dumpsite (Manzanarez, 2009).

SLP, thence, counts with a very recently established waste collection service that regularly picks up the garbage bags from SLP´s households. The recollection service in SLP is free of charge, even though the people from the voluntary collection service gladly receive tips from the citizens.

Figure 10: Recycling Initiative in SLP (Töpfer, 2012)

Unsurprisingly, SLP does not count yet with a recycling system, although some efforts from private initiatives have been made, offering the collection and sometimes also buy selected resources like paper, glass, aluminium and plastics. At some public places like schools, shopping centres and at the University, separated garbage bins are installed and special wastes like batteries are collected, but the efforts are not very well implemented as people stick to their common consumption habits. One very prospering initiative is Recikla - Conciencia Ambiental, which was founded in 2010 and has two installed recycling centres where citizens can bring their recycled residues generated at home, in the office etc. and receive credit transfers for the amount weighted (Recikla, 2012).
In May 2012 there was planned to set up new recycling trash bins with separation devices, provided by the company Plastic Omnium, in commercial centres in SLP (Govea Tello, 2012 pers. com.).

2.3.3 WASTE DISPOSAL

The wastes generated in the city of SLP today are brought to the dumpsite Peñasco that operates since 1995 on a size of 14ha where 929 tons per day were delivered in 2009 (INEGI, 2010). It is located in the zona milpillas of the city, had no design and continued operating under the same conditions for 18 years, causing environmental damage.
During the last 15 years the final disposal of urban solid waste in SLP had no compliance with the standard of ecological material and caused severe damage to the environment.
With the sanitation of the municipal dumpsite Peñasco in SLP in 2009, which reported a final exposure rate of 1000 tons of waste per day, the municipality wanted to set an example and show ecological responsibility (Red Ambiental, 2011).

The accumulation of more than 10 million tons of trash that reached a height of up to 22 meters at the dumpsite Peñasco had generated the inevitable collapse of the site and provoked the authorities to enact an emergency situation (Red Ambiental, 2011).

Figure 11: One of the waste receiving cells at Peñasco (Töpfer, 2012)

Given these circumstances, the council of SLP proceeded to start a remediation and sanitation project as well as the construction of a new cell for the final disposal of USW, holistically including the improvement of the properties at the site in order to increase its operational efficiency and effectiveness in 2009.

To the favour of the environment and the population, the dumpsite is now since 4 years controlled and sanitised. Today the remediation of Peñasco is a fact and a new cell, technically manufactured according to the Mexican Official Standard 083 was established. That gives the authorities of the municipality time to find other suitable sites in SLP for the deposition of their garbage for the next 20 or 30 years.

Until 2009 the wastes were also brought to the landfill Santa Rita in SLP that operated on 40ha and has a capacity of 79.818 m^2. 340 tons per day were said to be deposited there (INEGI, 2011).
Santa Rita stopped to comply with the Official Mexican Norm 083 and was socially closed in 2009. Because of its close location to the community, completely surrounded by houses, the operations on the landfill caused conflicts with the local community that did not want more garbage to get delivered there, causing problems for health and environment. Today it is closed, covered by plastic foil and waiting for further decisions. The landfill Santa Rita is also registered as passive system for venting of landfill gas (LFG) only, no LFG flaring, by the UNFCCC CDM (2010).

Both, the dumpsite Peñasco and the landfill Santa Rita, are project of the Mexican company ENERGREEN for the extraction of biogas since April 2010. There is no more official news until yet. The municipality of SLP explains reasons of bureaucracy make the work difficult. The company is still investigating the potential biogas and in negotiations with the municipality and CFE.

Around 800 pepenadores work at the dumpsite Peñasco and earn around 1.000 MX$/week, that correspond to around 58€ or 75US$ (Govea Tello, 2012 pers. com.).

They need to pay an entrance fee of 8 MX$ to the dumpsite for one truck, regardless how much volume and amount of garbage they bring (Govea Tello, 2012 pers. com.).
In chapter 1 it was mentioned that pepenadores on Mexican landfills recover around 6-10% of wastes that will be recycled from commercial site. The Department of Urban Sanitation of the Municipality of SLP also estimates that the local pepenadores at Peñasco separate on a good day around 10% of the total wastes (Govea, 2012 pers. com.) that can be recovered and sold to intermediates for further industrial processing.
Actual prices on the waste recovery are unknown to the municipality as they do not want to be seen as intervention or competence to the pepenadores' business.

2.4 DISCUSSION

As it can be noted, it is very difficult to make a concrete statement about the amount of USW or MSW generated in SLP as there is no monitoring and no recent numbers available. The presented calculations base on estimations, predictions and comparisons to experienced data. Comparing the data on waste generated for the city of SLP with studies in other Mexican cities that were presented in chapter 1, similarities can be noted, but do not replace real data.
Formerly, the present investigation´s intention and objectives included a waste characterisation study in the city of SLP, but time and labour resources were found to be limited. It would have only been possible to conduct a small analysis, applying a simple random sample distribution with a sample size of maybe 30 garbage bags picked up at different areas of the metropolitan zone of SLP, which, moreover, would not have been representative to be compared to other studies, to be extrapolated to show an overall picture of the generated waste amount in SLP or to be used for further potential biogas calculations. This is also why a detailed characterisation of HSW and MSW is an urgently needed first step to develop sound strategies for the municipal waste management in SLP.

The World Resources Institute (In Gonzalez, 2011) stated that "USW is a heterogeneous material and its generation rates and composition vary from place to place and from season to season" but the corresponding data values estimated in SLP are similar in other mid-size Mexican cities. This would suggest that the daily per capita generation rate of HSW is relatively homogeneous among mid-size and large urban areas in Mexico. On the other side, the generation of MSW in deed is dynamic and heterogeneous, as it is determined by socioeconomic variables with differential impact incidence according to the area analysed (Rathje et al., 1992; Buenrostro et al, 2001). This is why the analysis of the generation and composition of MSW must be constantly updated in order to propose a classification that enables the use of the socioeconomic data for the indirect assessment of the waste sources. "With the economic activity involved it is also possible to forecast the characteristics of SW generated" concluded Buenrostro et al. (2001). This would mean useful information for implementing surveys on waste composition and integrated solid waste management (ISWM) strategies.

With the purpose of improving the current waste management system and having the information presented, it is recommended to conduct a quantitative waste generation assessment and an analysis of the potential treatment options for those wastes. A Lifecycle Inventory Assessment of SW management constitutes a valuable tool that allows the establishment of different ISWM scenarios and, from them, to provide crucial information for decision makers to select the best option that accomplishes technical feasibility, social, economic and environmental sustainability.

The current waste management system in SLP is characteristically inefficient. Further work has to be done in the area of environmental education to call attention for valuable resources, show consumption patterns, habits and possibilities to reduce, reuse and recycle to also add a recycling system to the municipality.

2.5 CONCLUSION

In the city of San Luis Potosí, urban sprawl implies pressure on the existing infrastructure, with implications for buildings, public transport, road networks, water quality and access, waste collection, and sanitation. Extreme weather changes cause floods on the improperly planned and constructed streets, meanwhile, these and existing highways still encourages residents to use private cars, affecting the city´s air quality.

Generally, efforts should be devoted to obtain better estimates of the generation rates and composition of HSW and MSW. In this study, a combination of data from older studies in other cities, rough statistical estimates for the municipality of SLP and personal comments by people involved in the sector, provided the background for the projection and estimation of the waste generation amount, organic share and disposal rate of MSW in SLP. However, the real sources contributing to MSW could not be determined. Studies particularly focusing on these issues would be very useful for future decisions.

Another aspect that derives from this investigation is the important role of the pepenadores in the waste management and separation of garbage. In the case of SLP a sound waste management strategy should involve the optimisation of the pepenadores' situation. A solution of how to involve them to their benefits by respecting their needs should consider

- Improving their organisation and labour conditions
- Providing training to them and

- Incorporating them to the formal working sector, rather than discouraging or limiting their activities (Bernache-Perez et al., 1999).

The present investigation has given a rough characterisation and description on how wastes are handled in the city of San Luis Potosí, how the recollection service works and where the wastes are disposed. This information on the situation at the local disposal site and existent equipment and possibilities will be necessary for the following analysis of the biogas potential. Some statistical data on waste amounts could be obtained, despite still; these data should be supported by in situ composition studies of the wastes at the landfill and can here only provide background information for future planning.

CHAPTER 3: POSSIBLE WASTE TO ENERGY STRATEGIES

3.1 INTRODUCTION

Having understood the energy and waste needs and energy structure in Mexico in chapter 1, analysed the municipal waste management practices and having estimated an amount of MSW generated in the city of SLP in chapter 2, it is now time to look at the opportunities on how to combine the two sectors of waste and energy and find beneficial strategies that can improve or solve some of the problems that occur in this respect.

"Globally, 140 billion metric tons of biomass is generated every year from agricultural, forestall and industrial activity" states the United Nations Environment Programme in 2009 and recognised an enormous amount of energy, "equivalent to approximately 50 billion tons of oil" that could be converted from biomass and raw material (UNEP, 2009). On the other hand, it was estimated that around 1.3 billion people worldwide still have no access to electricity (IAEA, 2009). The strategy to convert wastes into energy can substantially displace fossil fuels, reduce GHG emissions and "represents an attractive potential for large-scale industries and community-level enterprises", convinces the (UNEP) 2009.

The energetic conversion from biomass wastes to biogas could be crucial key to conservation and development strategies for Mexico and some waste to energy implementation possibilities will be presented in this chapter.

Figure 12: Biogas Source Chain (Töpfer, 2012 icons)*

Biogas or landfill gas is classified as tertiary energy, because its sources are generated by solar energy. The primary energy would be identified as sunlight and the secondary energy is the biomass. Methane and $C0_2$ that are exposed by the degradation process can be converted into useable end energy in form of heat, gas, fuel and electricity. Biogas is classified as chemical energy type, because it is elaborated by chemical processes from the activity of microorganisms during a natural process called anaerobic digestion. It happens basically in any natural organism, when bacteria degrade biological material in the absence of oxygen. Biogas can be generated by any biomass, e.g. agricultural crops, plants, vegetables. However, the current critical discussions agree that these crops should rather provide food instead of biofuels at first hand. A more intelligent solution is the usage of organic wastes like e.g. livestock excrements, sewage, vegetable oil remains, food wastes etc. that will be produced anyhow.

Also the deposited wastes at a sanitary landfill undergo anaerobic digestion and the released GHGs often contribute to climate change rather than being utilised for energetic purposes. Likewise typical biogas plants, landfills can also be conceptualised as a biochemical reactor; waste and water are the inputs while gas and leachate are the outcoming products (Machado et al., 2009). Waste to energy possibilities include recycling approaches, biogas plants, landfill gas capture, combustion of wastes and several other technologies and political instruments that also give financial incentives.

To reduce methane emissions from landfills two approaches can be considered:

- Change the waste management practices to reduce the waste disposal at landfills by adding composting and 3Rs programs
- Capture the CH_4 and flare it or use it for energy

Methane recovery for the exploitation of energy is the most beneficial approach and is the focus of this analysis, even though a properly working waste management forms the base of a well working biogas or LFG plant and a separation of the wastes at its source of generation simplifies the biogas exploitation at the plant enormously. After recycling possibilities, some biogas technologies will be presented. Later the final energy end use options will be analysed and implementation requirements be shown.

3.2 RECYCLING APPROACHES

3.2.1 REDUCE, REUSE, RECYCLE

Figure 13: Recycling bins in Nayalit (Töpfer,2012)

Growing demand for renewable natural resources leads the path rather to a reasonable utilisation of those resources for our needs as USW contain several by-products that can be reused as raw material and therewith help reducing the volume and amount of wastes that are sent to the final disposal site (Maldonado, 2006).

In most Mexican municipalities rubbish collection service is free for all citizens but a waste management system that includes reduction and recycling could also be an economic motivation for the state or municipality as also costs associated with waste transportation to the sanitary landfill will reduce. Gonzalez (2011) recognised that "commercial recycling collection programs are uncommon in Mexico, and the recycling

rate is a mere 3% of municipal waste, compared to 24% in the USA and around 35% in many European countries".
The biggest problem is formed by consumption and behaviour habits. We have seen that the waste management system in SLP was established only four years ago and recycling initiatives are still in development. For this matter, mostly educational programs are needed that explain production chains and sensitise the people for the generation and disposal of products and services they consume. Only by a reduction, reutilisation and recycling (3Rs) of products, the waste that we generate can be minimised to large extent.

In order to realise recycling activities, the necessary facilities that give the possibility where to recycle need to be installed. These initiatives can come from commercial site, private action or the municipality. Financial stimulations and commercial incentives e.g. the "bolsa ecologica" promoted at several supermarkets, a reusable textile bag to bring with you instead of numerous plastic bags that are commonly used at the supermarkets, can make big differences. Also packaging regulations could be modified by law or by consumption behaviour.

However, environmental knowledge and awareness is a task among the responsibilities of each citizen that daily generate wastes. It is the consumers decision whether to buy the cookies that are enwrapped each one separately and are in fact more garbage than product, or a big box that has only one carton package. Also paper reutilisation is an easily applicable method to reduce wastes; double sited printing should be standard setting for printers etc., avoid disposables, switch off lights, energy and running water devices when not in use, consider walking, riding the bike or taking public transport means instead of the car for every meter and so on. The possibilities are multiple to reduce waste and energy consumption and contribute responsibly to the conservation of the environment.
These little actions show good education, civilised awareness and willingness to the government and may induce changes. For real difference in the waste management system and noticing results and changes at the generation and disposal site, a new operational system would be needed that the municipality, state or federal authorities are responsible for. The presentation of a law in this respect would also mean a good incentive.

A problem of separation programs is the removal of the products that the waste collectors sell to specific buyers of each of the resources and intervenes with their businesses. "Municipal solid waste collection […] is a business that pays good dividends to certain social groups. Successful programmes of waste minimisation through source separation and by-product recycling could reconfigure the distribution of benefits and, therefore, become a cause of social conflict, if no alternatives are sought to satisfy the majority of those involved in the waste business" concludes Maldonado (2006).
It was recognised that the commercialisation of waste by-products as resource like PET, glass and aluminium, is only profitable when managed in great volumes.

3.2.2 INTEGRATED SOLID WASTE MANAGEMENT

Modern human societies have a number of reasons for studying the process of solid waste generation. For purposes like urban development planning, the amount, composition, generation, disposal and management of urban solid wastes as well as the consumption behaviour must be known also to establish integrated solid waste (SW) management strategies (Bernache-Perez et al., 2001).

Integrated solid waste management (ISWM) is defined by the UNEP (2007) as a "strategic approach to a sustainable management of solid wastes covering all sources and all aspects, covering generation, segregation, transfer, sorting, treatment, recovery and disposal in an integrated manner, with an emphasis on maximising resource use efficiency". An ISWM in the city of SLP needs to be established by the municipality and would involve many actors and stakeholders, as well as the adoption from SLPs citizens.

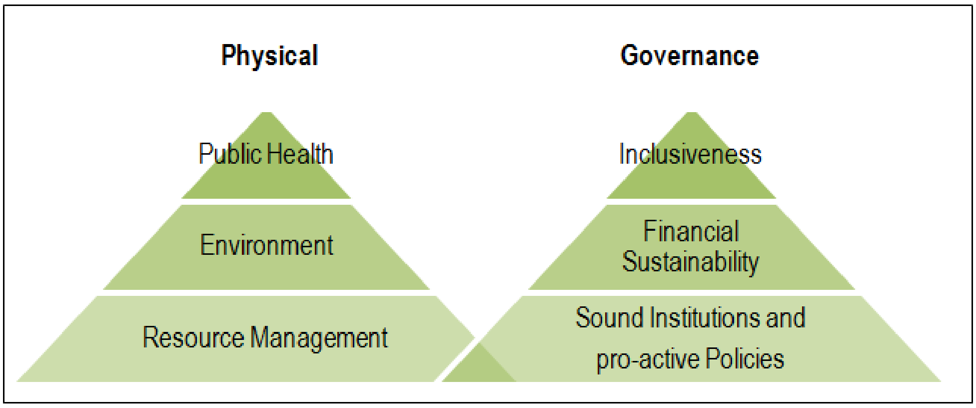

Figure 14: The Concept of ISWM (Töpfer, adapted from UNEP, 2007)

Many authors agree that in Mexico the lack of government funds impedes the implementation of proper waste management and final disposal systems and also Maldonado (2006) states, that "in many Mexican municipalities such programmes could represent between 20% and 50% of the annual budget". Most initiatives have been established uncontrolled and without any concept to define best suited strategies for the area to allow the evaluation of results and correction of errors (Schübeler et al., 1997).

3.2.3 MECHANICAL SEPARATION

We have discussed widely the environmental and health risks on open landfills. The enormous generation of urban, often also hazardous, solid wastes and their inadequate treatment and disposal make open landfills dangerous to the environment and the local population. As it is the intention to show in this document, MSW can be used to generate energy as they contain still valuable resources. Capturing those resources and converting them into energy is what at a waste to energy (WtE) facility is determined as resource recovery. Physical or mechanical separation uses a variety of equipment or manual labour to prepare, divide, and sort waste into items of similar size, nature, or quality. Physical or mechanical separation of wastes is often an essential part of composting and combustion facilities. The mechanical separation of the non-combustible fraction of the wastes for example, results in the production of refuse derived fuel (RDF). Similarly, with the process of mechanical separation biodegradable materials can be used as compost or fertiliser (Minnesota Resource Recovery Association, 2011).

A variety of recycling options exist as part of the operations of WtE facilities. Some have material recovery facilities (MRF) designed to remove recyclable material (ferrous, aluminium and cardboard) prior to combustion, others remove ferrous from the ash and recycle it. Recycling is a vital component to a sustainable waste solution. Studies show that WtE facilities complement recycling efforts and communities participating in WtE facilities typically have higher recycling rates. A response to the critical material removal for waste collectors could be the employment of these social groups at the mechanical separation facility, as these people can be considered best experienced.

During the next intercept the most commonly used options on biogas technologies will be shortly presented. Several technologies have been developed that make the processing of MSW for energy generation cleaner and more economical than ever before, including combustion, landfill gas capture, pyrolysis, gasification, and plasma arc gasification (EESI, 2009). The methods by which methane is recovered from landfills involve the use of a series of wells and vacuums that collect the gas. The methane is then sent to a processing and treatment facility, which typically operates on-site at the landfill but can be located between the landfill and the end user at a separate location or at the site of the end-user. Several end use functions exist for gas that has been collected, processed and treated (Williams, 2008) and will be reviewed at the end of this chapter.

3.3 BIOGAS TECHNOLOGIES

3.3.1 INCINERATION PLANTS

The most commonly known waste to energy (WtE) facilities are incineration plants. The heat from the combustion of wastes in a chamber at high temperatures is used to generate steam in boilers. The steam drives steam turbines coupled to generators to produce electricity. These facilities can work with or without energy and material recovery. The process starts with collection vehicles delivering incinerable solid waste to the WtE plants, where their payload is weighted, crushed to reduce the volume and improve the burning efficiency. The incinerator is heated to temperatures between 800 to 1.000°C, what makes the load of solid waste reduce to about 10% of its original volume in about five hours. Emissions need to be controlled and monitored by filter systems that remove pollutants from the gas. From the volume of the original garbage, around 10% becomes ash, ferrous material is removed to be sold and recycled and the rest becomes energy (NEA, 2002). The benefits of these include the treatment or processing of the trash to make it non-hazardous, non-infectious and less harmful to humans and the environment and reducing the total waste volume requiring final disposal, thereby reducing the amount of land needed for landfills (Minnesota Resource Recovery Association, 2011).

While old combustion facilities often had high emissions toxic compounds, recent regulatory changes and new technologies have significantly reduced this concern and today ensure that modern WtE facilities are cleaner than almost all major manufacturing industries (Environmental Technology Center, 2000; EESI, 2002). Regulations by EPA in 1995 and 2000 under the Clean Air Act have succeeded in reducing emissions of dioxins from WtE facilities by more than 99% below 1990 levels, while mercury emissions have been by over 90%. EPA (2006a) noted these improvements in 2003, citing waste to energy as a power source "with less environmental impact than almost any other source of electricity".

3.3.2 LANDFILL GAS CAPTURE AND FLARING

When wastes on landfills undergo the process of anaerobic digestion, gases will be emitted. The released biogas or landfill gas is composed of approximately 50% CO_2, 50% methane and trace amounts of other gases. To prevent these GHGs to be emitted to the atmosphere, the landfills must be properly closed to combust the gas by oxidation, as air contains 21% of oxygen. The disposal site can easily be tapped with a plastic foil.

Closed sites without a methane gas recovery project usually cover the landfill with a substantial soil layer, so that the methane emissions can be consumed by methanotroph bacteria that use methane as a source of carbon and energy. Three types of liners typically are used: mineral, geomembranes and composite liners. Mineral liners are made of clay, mudrocks, and soil bentonite admixtures, geomembranes are thin polyethylene layers and composite liners are a combination of a geomembrane with some form of mineral lining (Williams, 2008).

There are several materials that can be used and were found to be suitable. High density polyethylene (HDPE) is a tough plastic film that has the disadvantage that it can be degraded by chemicals. Flexible Membrane Liners (FML) is a single liner made of two parts, a plastic liner and compacted soil, usually clay that is often fractured and cracked. Here it has to be made sure that the soil is permeable to liquids or gases. Evapotranspiration (ET) Landfill Cover Systems use water balance components to minimise the percolation, it also has less costs. The costs of these plastic foils are generally between 80.000US$/ha and 500.000US$/ha.

Once a landfill is properly closed, the activity of microorganisms generating biogas during the degradation is favoured and can be extracted in chimneys from the landfill.

The easiest solution to avoid the release of dangerous GHGs to the atmosphere is flaring those gases with an excess gas burner at the top of the gas socket.

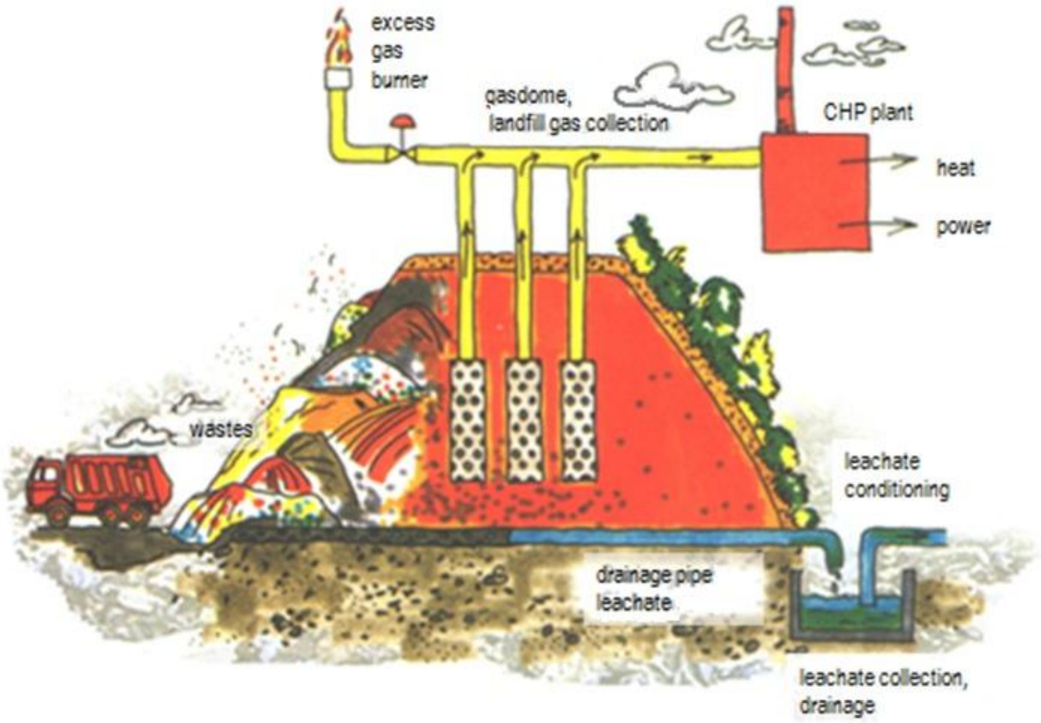

Figure 15: The LFG Capture Principle (Stadtwerke Karlsruhe, 2011)

To make usage of the biogas, operators dig a series of wells into the landfill and can capture between 60% and 90% of the gas emitted, depending on the system design (EPA, 2009). The captured gas is then pumped to a central facility where the methane can be refined to pipeline-quality renewable natural gas, flared, or used for heat or electricity generation on the site (Guzzone and Schlagenhauf, 2007). However, landfill gas systems require a large amount of landfill space, and a significant amount of climate warming methane will still be released.

3.3.3 BIOGAS PLANT

Wastes can be turned into several types of biofuels, biofertiliser and biogas that generates electricity or heats homes. Biogas usually contains 50-75% methane, carbon dioxide and traces of other gases and is the chemical equivalent of natural gas. The composition of combustible biogas is shown in table 3 (Fachagentur Nachwachsende Rohstoffe, 2010).

Compound	Chem.	%
Methane	CH_4	50-75
Carbon dioxide	CO_2	25-45
Water	H_2O	2-7
Oxygen	O_2	< 2
Nitrogen	N_2	< 2
Ammonia	NH_3	< 1
Hydrogen sulphide	H_2S	< 1

Table 3: Composition of Combustible Biogas (FNR, 2010)

The process of generating biogas contains several steps. Firstly, the waste, that can be MSW or come directly from wastewater treatment plants, farms, slaughterhouses or restaurants, will be delivered to the biogas plant either by tubes or by trucks and will be mixed together, preferably with water. The waste is pumped into a tank where it is preheated, including with steam for around one hour at 158°C.

The sludge created from the waste than flows into oxygen-free tanks where it remains several days at 100°C. Wastes from wastewater treatment plants remain in the tank for 20 days, while solid wastes need 40 days. Microorganisms´ activity in the tank converts the organic material into biogas and as by-product remains bio-fertiliser (figure 17).

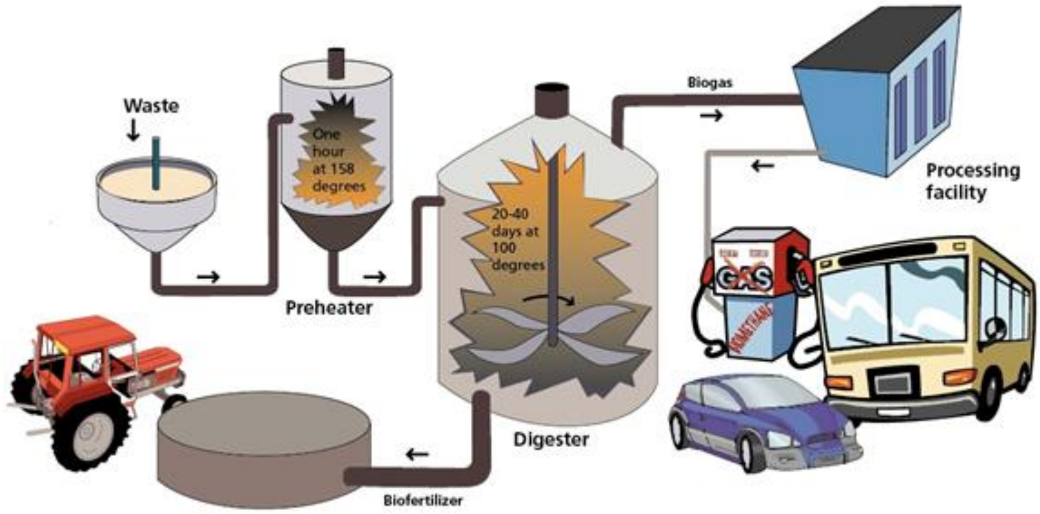

Figure 17: Biogas Conversion (Swedish Biogas International, 2010)

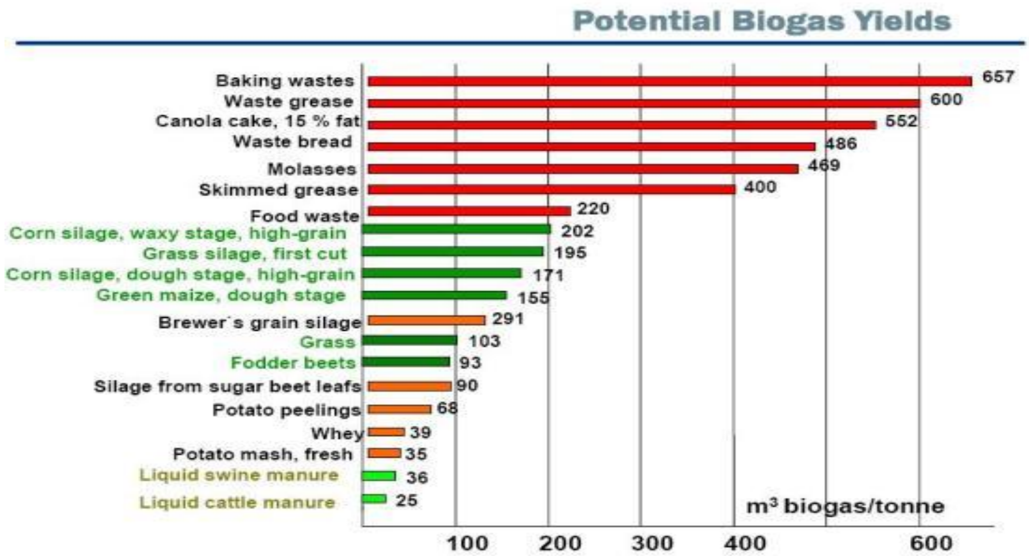

Figure 16: Materials Best Implemented (Ceeres, 2010)

Biofertiliser can also be upgraded to a higher methane concentration of about 97%, the quality of natural gas, which is then called bio-methane by decreasing the proportion of carbon dioxide and contaminants in the gas by a separation process (Swedish Biogas International, 2010).

Studies on the materials best implemented for the generation of biogas have shown that the biggest potential biogas yields, measured in the content of carbon and methane (Ceeres, 2010) are in fact wastes rather than energy crops. Figure 16 shows that food wastes that contain big amounts of fats and greases like baking wastes and bread can provide from 400 to 600m^3 biogas per ton and bring a higher outcome than vegetable plants like corn and maize silages.

3.3.4 PYROLISIS

In a pyrolisis process the wastes are heated in the absence of oxygen at temperatures ranging from 288 to 704°C (Sipilä, 2002). That process releases a gaseous mixture called syngas, a liquid output, both of which can be used for electricity, heat, or fuel production and also creates a relatively small amount of charcoal. While this process results in relatively low net GHG emissions and has high conversion efficiency, technical difficulties have prevented its implementation on a commercial scale. The biggest barrier has been the difficulty of removing enough oxygen from the MSW to sustain a strong reaction (Schilli, 2004; EESI, 2009).

3.3.5 GASIFICATION

Differently to pyrolisis, gasification includes small amount of oxygen when MSW are heated at a chamber and presents temperatures ranging from 399 to 1649°C. This also creates syngas, which can be burned for heat or power generation, upgraded for use in a gas turbine, or used as a chemical feedstock suitable for conversion into renewable fuels or other bio-based products (Zafar, 2009). Gasification is economically viable at a small scale and tends to emit lower amounts of SOx, NOx, and dioxins than combustion. However, gasification has proven difficult to apply on a large scale and is not yet cost competitive with combustion (EESI, 2009).

3.3.6 PLASMA ARC GASIFICATION

Superheated plasma technology is used to gasify MSW at temperatures of 5538°C or higher, an environment comparable to the surface of the sun. The resulting process incinerates nearly all of the solid waste while producing from two to ten times the energy of conventional combustion (Westinghouse Plasma Corporation, 2007). The solids left over are chemically inert, and can be used in paving surfaces (Bhasin, 2009).

While the technology is still relatively immature, several demonstration facilities have been built to provide conventional electricity, while hybrid facilities that combine conventional and plasma gasification to create ethanol are also in development (Sims, 2008, EESI, 2009).

3.3.7 BLUE TOWER TECHNOLOGY

Unlike other biomass utilisation technologies, Blue Tower technology utilises regenerative feedstock and can be understood as multi-feedstock technology as different materials such as garden wastes, food wastes or animal manure can be used. Blue Tower technology does not depend on a single feedstock or its cost-efficient availability, which implies a multitude of location-specific potentials. The outcome of Blue Tower technology is Blue Gas, a premium-quality gas that is high in hydrogen and includes other gas components, which deliver high heating values. It can be provided as a fuel gas or can be used directly in gas motors for regenerative electricity generation. It also serves as a raw material for synthesis gas and can be used as a sustainable hydrogen and energy supplier.

Compared to combustion of biomass or other processes, the decomposition of the feedstock (pyrolysis) and refinement of the gas produced (reforming) occurs in separate locations, which allows more precise control of the process steps and increases the overall efficiency of the plant. Differently to the process of anaerobic digestion in a biogas plant, Blue Tower technologies operate at temperatures above 500°C. The feedstock will be fully mineralised and the final gas product contains a large amount of hydrogen which more or less does not exist in biogas (Solar Millenium AG, 2012).

3.3.8 ORGANIC RANKINE CYCLE FACILITIES

The Organic Rankine Cycle (ORC) describes the use of an organic, high molecular mass fluid that changes from liquid to vapour and occurs at a temperature range from 70-300°C, which is lower than the change from water to steam. Therefore, lower temperature sources, such as biomass combustion or industrial waste heat can be used, which the fluid accepts for a rankine heat recovery. This heat can be converted into useful work and finally into electricity. The working fluid, e.g. organic oil, is pumped directly to a boiler where it is heated, evaporates, passes through a turbine and is finally recondensed.

ORC is mostly applied for waste heat recovery in heat and power plants (e.g. a small scale cogeneration plant on a domestic water heater) or for industrial and agricultural processes. The power plants can provide an installed capacity between 300-400 kW, some up to 1MW. Since in ORC facilities low pressure and only a steam boiler will be required, the investment and maintenance costs are considerably low. Further advantages are the long operational life of the machine as the working fluid, unlike steam, does not erode and corrode, the relatively small amount of input fuel needed and the fact that ORC plants can operate at partial loads in a range between 30% and 100% load (Declaye, 2009).

Once the biogas quantities that can be extracted during a period of years are estimated, the suitable technology is analysed, possible end use utilisation options need to be studied. A common method of controlling methane emissions from landfills is to install a gas collection system on the landfill to collect and convey the methane by series of wells to a gas control system. This system directs the collected gas to a central point where it can be processed and treated depending on the ultimate use for it. From this point, the gas can be destroyed by flaring or can be used to generate electricity, replace fossil fuels in industrial and manufacturing operations or be upgraded to pipeline-quality gas (Guzzone and Schlagenhauf, 2007).

3.4 FINAL END USE OPTIONS

3.5.1 BIOFUELS

Depending on the technology that will be utilised, amount and quality of the biogas or LFG generated will vary. LFG can be collected and transported for the direct use as fuel for applications in boilers, industrial processes, vehicle fuels, gas-fuelled engines etc. Through a process called biomass to liquid (BtL) or dry fermentation, biofuels can be produced. Another alternative, which requires further refinement of the gas, is to convert the methane into a pipeline-quality transportation fuel for alternative fuel vehicles (M2M, 2011).

For example, the landfill in Queretaro reported the quantity of the recoverable amount of biogas enough to develop a system for using biogas as fuel for electric power generation. The study in 2005 estimated that the presumable costs for an initial construction collection system and the control of biogas were 1.1 million US$, while the costs for implementing an electric power plant of 2.12MW with internal combustion generators using the biogas as fuel was 2.76 million US$. They concluded that the best option would be the sale of electric power to the municipal government, which currently happens through SIMEPRODE (SCS Engineers, 2005a; EPA et al., 2011).

3.5.2 COMBINED HEAT AND POWER or Cogeneration

Today, biogas is mostly used to produce electricity and heat in cogeneration plants that are located on the generation site. A gas engine powers a generator that produces electricity that will be fed into the local grid and a heat exchanger uses the exhaust gases and the engine cooling water to produce heat. Combined heat and power landfill gas to energy (CHP LFGE) projects will produce electricity as well as shaft power, hot water, steam, chilled water or dehumidification. Combined with LFG, CHP projects cogenerate electricity and thermal energy, usually by using waste engine heat to produce steam or hot water. LFG cogeneration projects that use turbine or spark ignited (SI) reciprocating engine generators have mostly been installed at industrial operations. Advantages of cogeneration are the greater overall efficiency from waste heat recovery of up to 80%, more energy outcome and the flexibility of hot water or steam generation from the recovered heat in specialised CHP systems. CHP can provide industrial and commercial facilities with greater reliability and increased process flexibility compared with conventional generation methods (Guzzone and Schlagenhauf, 2007). Because cogeneration technology is proven, CHP projects represent also low technology risk. However, these systems are usually more costly to implement and there needs to be requested a license for cogeneration to CRE (EPA et al., 2011).

3.5.3 GAS FEED IN

As biogas contains 50% methane, which again is a hydrocarbon main component of natural gas, it has the same utilisation conditions. Whereas in CHPs that use the heat and electricity at the site, most of the produced heat will be released unused, the generated biogas could be refined into natural gas and fed into the gas grid and be used in places other than heating. In this process the energy production and consumption will be spatially and temporally decoupled and less energy will be lost (EnBW, 2012).

Moreover, it was said that burning methane is more efficient than using natural gas, since LFG has approximately half the heat content of natural gas and burns at a lower temperature (Williams, 2008). Purification from biogas to biomethane fed into the natural gas system permits a site-independent and efficient use, a highly efficient power generation, optimum heat utilisation or the use as fuel at the gas station. Although the technical requirements for processing and feed-in of biogas into the gas network can mainly be met, the realisation is impeded by logistic, administrative, legal and other matters. CRE, the energy regulating entity in Mexico, is also responsible for natural gas and their activities include the generation, supply and sale of electricity to the users.

3.5.4 GRID CONNECTION TO THE CFE NETWORK

Likewise biogas feed-in to the natural gas system, biogas can also be connected to the electricity grid. Conditioned at a CHP plant, biogas can be transformed into electricity. As it was shown in chapter 1, the law defines that the electric power generated by the extraction of biogas is for self-supply and -consumption only. If there is surplus in electricity production, then it can only be sold to CFE to a given fee. This requires having signed a contract of sale for self supply of energy with CFE. To sell electric energy generated by methane from the landfill to a government or public company, certain rules and several actions to CFE and CRE must be followed. If an interconnection to the national grid is possible, additional investment must be kept in mind to comply with the requirements of CFE. We have seen in chapter 1 that also the electrical network of transmission and transportation lines is CFE´s property, why there has to be paid a tariff (MX$/kWh) for the transport of the generated electrical energy from the landfill to the desired consumption point. Calculating these costs is part of the feasibility study considering the technical implementation, the location of the landfill, the load of the electric system and related services required (EPA et al., 2011).

Another waste to energy (WtE) possibility and end use option is not a technology but a mechanism that indirectly produces energy by the generation of energy sources and is recognised in the formation of carbon credits by emission reductions, which the wastes on the landfill would have caused when not exploited for electricity generation.

3.5 EMISSION REDUCTION

Methane is considered the second most dangerous GHG emission source after CO_2, accounting for 14% of global GHG emissions in 2005. Although released in fewer quantities than CO_2, its potential contribution to global warming is 21 times higher than that of CO_2 (IPCC, 2007; GMI, 2011). The global atmospheric concentration of methane has increased from a pre-industrial value of about 715 parts per billion (ppb) to 1.782 ppb in 2007 (IPCC, 2007) and is projected to grow up to 7.904 million metric tons of carbon dioxide equivalent (MtCO2eq) by 2020 (EPA, 2006b). The IPCC Report (2007) declares with “high agreement and much evidence” that global GHG emissions have grown since pre-industrial times with an increase of 70% between 1970 and 2004.

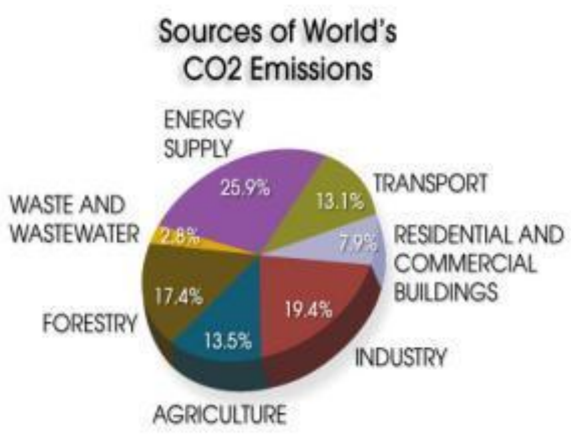

Figure 18: Share of Wastes in World´s CO2 Emissions (pbs, 2008)

Country	2005	2010	2015	2020
Mexico	33.3	35.5	37.4	39.2
USA	130.6	125.4	124.1	123.5
EU- 15	-	46.3	-	32.7
World	747.4	760.6	788.1	816.9

Table 4: Global Emissions [MtCO2eq] (EPA, 2006; IPCC, 2007; GIM 2011)

Globally, landfills are the third largest anthropogenic source of methane, having a share of 13% of global GHG emissions. According to projections of methane emissions generated by municipal landfills in the world, they "tend to increase from 747.4 MtCO2eq in 2005 to 816.9 MtCO2eq for the year 2020, which means a 9,2% increase" states the GMI (2011). The Global Methane Initiative (GMI) was founded in 2004 as Methane to Markets (M2M) Alliance by 14 countries, among them Mexico. With the incorporation of several private entities and international organisms, reaching 38 country members, they turned to GMI in 2010.

Landfills are one of the four focus areas for the harvesting or burning of methane in order to reduce GHG emissions, improve air quality and promote the economic growth by the generation of energy using methane. The chart of figure 18 from the 2007 IPCCC Climate Change Assessment Report shows the contribution by sector to the total anthropogenic GHG emissions in 2004 in terms of CO_2 equivalent. Even though waste and wastewater has a minimum share of 2,8% to global CO_2 emissions, they still are listed as a single source, responsible for climate change by releasing dangerous GHGs that result in global temperature changes that affect our climate systems. (IPCC, 2007; pbs, 2008).

The projection of methane emitted from municipal sanitary landfills in emerging and developing countries' emissions are said to increase at tolerable until alarming levels, whereas in industrialised countries they are most likely to decline. In Mexico, methane emissions from 2005 to 2020 are projected to increase from 33,3 to 39,2 MtCO2eq, which are 17% (EPA, 2006b; GIM, 2011) (table 4).
On landfills, the main factors that influence the amount of methane gas are mainly its construction design and the types of organic materials deposited. Given the sustained growth both for the population and economy in emerging countries like Mexico, emission reduction will be quite a challenge.

3.5.1 THE INTERNATIONAL EMISSION TRADE SCHEME

Internationally, the issue of reducing climate change emissions rests primarily in the agreement of the Kyoto Protocol (KP). The Kyoto protocol defines three innovator flexible mechanisms, integrated by the Clean Development Mechanism (CDM), Joint Implementation (JI) and International Emission Trading (IET) that promote projects to reduce GHG emissions. Inside the Bali Action Plan of 2007 a new mechanism called NAMAs was created. Nationally Appropriate Mitigation Actions (NAMAs) recognise that different countries may take different nationally appropriate actions to reduce emissions and achieve climate goals. Their applications are still in development but today handled as to likely replace the CDM in the future. Currently there are four NAMAs in Mexico proposed focusing on transport and building (NAMA Database, 2011).

CDM is designed to encourage industrial countries to invest in emission-cutting projects, mostly in developing or emerging countries. Successful projects create Certified Emissions Reductions (CER), which can be traded as carbon credits on the international emission market, being sold to compliance buyers in emitter countries who want to meet their own reduction goals for 2012. The transaction means the permission to emit GHG, benefiting those participants who do not emit or decrease their emissions and charging those who emit more than the allowed, while providing economic incentives to the participants, which may be governments as well as private or public companies. The reductions are measured in tons of CO_2 equivalent (tCO2eq) and translated to carbon credits, where one CER is equivalent to one ton of CO_2. The average price of a CER was around 8-15 US$/ton in 2007 (UNFCCC, 2010). Furthermore, it was noted that market prices show a close relation to the European Union Emission Trading Scheme (EU ETS).

A landfill to participate in the CDM needs to comply with a determined design and construction of the biogas capture system. It needs to be monitored and realise an established verification process. Landfill gas Clean Development (LFG CDM) projects rely on theoretical models to estimate the landfill gas generation by monitoring factors like the mass flow meter, the percentage of CH_4 in the gas (v/v) and the CH_4 destruction in a combustion device (Lee, 2007) and require a mayor quantity of 200.000 tons of waste accumulated. After the report from a special designated agency, the operator can apply for CER that can be sold to obtain revenues. For the delivering of CERs, all LFG CDM projects need to be controlled by the Executive Board (EB) of the Kyoto Protocol. In Mexico, potential landfill projects for the CDM have been identified, some of them will be presented later on. In 2007, 78 CDM projects were registered in Mexico, of which 71 are LFG projects (UNFCCC, 2010). According to data from BANCOMEXT (in UNFCCC, 2010) there are eight potential landfill projects with the possibility to be financially supported, among them the landfill Santa Rita and Peñasco in SLP.

Integration to Climate Change Mitigation (CCM) projects could mean feasible solutions to problems caused by improper waste management and waste disposal at open dumpsites. LFG CDM projects offer the chance to reduce GHG emissions while upgrading landfill management practices using revenue generated by the sale of emission reductions (Lee, 2007). Bancomext also supports the coverage of the costs for the registration with the United Nations Organisation (UNO) for CDM projects in Mexico and there is further the Mexican Carbon Fund (FOMECAR) that provides monetary contributions (EPA et al., 2011).

3.6 BIOGAS EXTRACTION IN MEXICO: EXISTENT PROJECTS

At this part some first initiatives and projects - some successful, some still critical – on how wastes can be converted into energy will be presented. Experiences from existing projects help to define the options on how the generation of biogas or landfill gas can provide electricity to the area, serve to make concluding assumptions on the determining factors which requirements are needed and which problems and challenges occur. Some people have already noticed the biogas potential from wastes in Mexican metropolitan zones and already initiated or implemented LFG projects at Mexican sanitary landfills.

It is worth mentioning that Mexico´s best working landfills are operated by private companies as they prevail with clear rules and transparency throughout the process. Among them are listed the landfill in Queretaro, Salinas Victoria in Nuevo Leon and the one in San Nicolás de Arriba, Aguascalientes. According to a study by the World Bank and the Ministry of Social Development (SEDESOL), there are at least 85 landfills in Mexico with potential to develop a project for the use or burning of biogas, which would contribute to a reduction of estimated 31 million tons of CO_2 a year (EPA et al., 2011). Currently some states and cities such as Ciudad Juarez, Culiacán, Aguascalientes, Monterrey, Merida, Mexico City-Neza, among others, use or burn biogas.

Figure 19: The Bordo Poniente Landfill in Mexico City (GTZ, 2005)

The Bordo Poniente in Mexico D.F. is said to be one of the biggest landfills of Latin America. With an extension of 3,75km^2, the landfill grows by a delivery of around 13.000 tons of wastes per day and is a huge methane source that caused many problems for the population of Mexico's capital. Since 1985, 76 million tons of wastes have been accumulated at Bordo Poniente, until it finally was closed in December last year.
The biogas potential there is estimated at 40-50 MW and was wasted all these years due to the lack of infrastructure. Finally, a project for the exploitation of it is in process as part of the national green plan (plan verde) (Hernández, 2009).
Millions of dollars are expected to be won through the trade of carbon credits as the project can imply a reduction of 2 million tons of GHG emissions annually. Also CEMEX, the national cement industry, announced to buy 3.000 tons of dry waste per day for the production of their bricks. A big problem at Bordo Poniente still, the same situation as at Peñasco in SLP, are some 1500 pepenadores dependent on the waste collection at the landfill.

In April 2010 the first biogas flaring and extraction plant was installed in Culiacán.
With an investment of 27 million MX$, the plant is operating with 55 interconnected extraction pits on 17 hectares of the landfill, which are converged by a gas extractor. The garbage is burned at over 800°C and a series of filters where the gases pass through convert these into non contaminating water vapour. 42.000 tons of biogas emissions are

avoided thanks to the program, profiting also the responsible company PASA with the sales of carbon credits.
“The challenge is enormous, the statistics indicate that there is still progress and tasks to complete" recognised Pablo Moreno Cota, Secretary of Social and Sustainable Development of the state "in Sinaloa about 3.191 tons of solid waste is generated daily of which only 33.07% or 1.055 tons are deposited at landfills as established by the Mexican Official Standard 083" (Hernandez in Linea Directa, 2010 in EPA et al., 2011).

The municipality of Aguascalientes received a bonus of 206.733,45€ in 2010, equivalent to around 3.400 MX$ for the environmental conservation in form of award from the company Biogas Technology. The capitals mayor, Adrián Ventura Dávila, explained that it is 10 million MX$ they received from the British company for the flaring of biogas as carbon credits during the present administration period (ICLEI-Mexico, 2010 in EPA et al., 2011).

Figure 20: BENLESA Agreement with the WB (BENLESA, 2010)

The Metropolitan Solid Waste Processing System LFGE Project in Monterrey is an example of a successful joint effort between city government and local business interests to turn LFG into electricity. Bioenergía de Nuevo León, S.A. de C.V. (BENLESA) is thanks to a strategic alliance of the private companies Bioeléctrica de Monterrey, S.A. de C.V., Sistemas de Energía Internacional, S.A. de C.V. (SEISA) and the government of Nuevo León (SIMEPRODE) one of the first biogas plants in Mexico and the first renewable energy project in Mexico and Latin America using the biogas from a landfill as fuel.
The plant is in operation since September 2003 and has an installed capacity of 12,72MW. The electric power generated is mainly used for public lighting, introduced to the CFE network, and for public transport. It meets approximately 80% of Monterrey’s public electricity needs (Williams, 2008; M2M, 2011) and provides enough electricity to light more than 15.000 homes. Monterrey is a city of approximately 4 million people and has a daily disposal of about 4.500 tons of MSW. The 12 million US$ project is partly funded by a 5 million US$ grant from the Global Environment Facility. The project has furthermore an emission reduction purchase agreement with the World Bank that is equivalent to 1 million tons of CO_2 (SEISA, 2007; BENLESA, 2010).

The most suitable end use option can be determined in a feasibility study that includes the estimation of the potential biogas and the needed equipment and processes. Sometimes local governments and managers claim the high costs of technology to access and benefit from the use of biogas, but in fact the main obstacles are governmental formalities and paperwork and technical and institutional incapacity to undertake the transformation of a landfill for the use of biogas. In the following part the necessary organisational requirements will be presented and which permits, applications and contracts need to be realised (cited all from the guide in EPA et al., 2011).

3.7 IMPLEMENTATION REQUIREMENTS

3.7.1 FEASIBILITY STUDY

First of all, if the landfill can produce electricity depends on two factors:

- The quantity of real biogas and potential biogas on the site
- The availability of financial resources for the construction of the needed infrastructure

These will be determined in a feasibility study, which requires time, money and involvement of various actors. A feasibility study includes an investigation on the framework of factors affecting the project, possible alternatives and surrounding conditions, the current status of the landfill, possible scenarios, costs, benefits and challenges and requirements like the time, material and human resources needed. City Council members may be designing complementary public policies that benefit the garbage collection and the current landfill operation.

In Mexico there are various companies with the experience and capacity to conduct such a study. In 2011 a feasibility study required approximately 100.000 US$, depending on the size of the landfill and implications (EPA et al., 2011). For the municipality exists the possibility to invite a private initiative to participate through the public and private fond Fondo Nacional de Infraestructura (FONADIN) administered by BANOBRAS, that can finance up to 50% of the project. The tender may also be covered by national or international institutions but should respect the local and state regulations on purchasing and tendering (EPA et al., 2011).

The feasibility study has the aim to determine the recuperation of biogas on the landfill, considering social, regulatory, economic, financial, environmental and institutional aspects and should not mix technical issues with socio-political actors.
From the two possible primary options for the biogas capture, flaring or exploitation, derive secondary options: auto consumption of the generated electricity, sell it to public and/or private organisms or trade the carbon on the emission market.

In Monterrey there were four potential biogas uses considered to their cost benefit relation:

- Generation of electricity and sales to the municipality or CFE
- Sales of the biogas to nearby industries

- Biogas supply for domestic use
- Purification of biogas for use as automotive fuel

A crucial point in the feasibility study is the estimation of the biogas that can be generated. This is a very technical process, which involves scientific formulas and actions in situ. Nevertheless, in this paper a theoretical calculation based on mathematical formula and the simulation software Model 2.0 for Mexico´s landfills will be presented in chapter 4 and can provide a rough estimate on the potential biogas yield.
The infrastructure required for the exploitation of biogas should be elaborated within the feasibility study, containing descriptions on the technical implementations of the biogas collection system like the pipelines, the combustion system for the flaring or the electric power generating machines installed, as well as the treatment and leachate installations (EPA et al., 2011).

3.7.2 PAPERWORK PROCESSES

There is a big difference between capturing and flaring of the biogas and its utilisation for electricity generation, both have the same origin but a different destiny, for which they also vary in the obtained biogas quantity, costs, political viability etc. and imply different paperwork requirements. Some formalities are to obtain permits for the biogas generation to electric power, others to build or improve required facilities at the landfill.

First of all, the legal territory status of the landfill needs to be secured and that it meets the official standards, mainly NOM-083. Secondly, several permits addressed to CFE, CRE, SEMARNAT and state and municipal government need to be processed.

The SEMARNAT defines environmental impact as "modification of the environment caused by human or natural action". An environmental impact assessment is strongly recommended for the evaluation of the social cost-benefit generated by a determined development project and also article 28 of the General Law of the Ecologic Balance and Environmental Protection (LGEEPA) includes those studies (EPA et al., 2011).

The Single Environmental License (LAU) is a multimedia tool for the direct regulation of federal jurisdiction in the industrial sector, such as in the flaring of biogas or the electricity generation. The LAU coordinates in a single evaluation process various environmental paperwork permissions an industrial entity needs to address to SEMARNAT. A LAU corresponds to one landfill and integrates the paperwork for the environmental impact assessment and emissions risk analysis, the generation of hazardous wastes and hydraulic services. The new license is appropriate for a landfill that began to exploit biogas (EPA et al., 2011).

Paperwork with the National Water Commission (CNA) needs to be realised if the project may affect groundwater aquifers, some type of wastewater to the drainage system or any water body. This needs the permission to deposit residuals (CNA-01-010). By law, the generated energy is only allowed for auto consumption, for which there would be necessary to fill out an application form for the permit of cogeneration of electric energy with CFE. A contract with the municipality and CFE is part of that process, to realise and maintain during its term the interconnection between the national electrical system, which is owned by CFE, and the generator. It also includes the construction of necessary power lines for the interconnection with the CFE network that must meet certain technical specifications.

A purchase agreement with CFE for Surplus Electric Power establishes the conditions and procedures for the case that the operator provides energy to CFE. Further a CFE agreement for the Transmission Service of Electric Power needs to be obtained, when the power generator cannot transport the electricity from its generation source to the consumption centres, given that the transmission is exclusive property of CFE. All of these requests addressed to CFE are free of charge. To avoid power shortages or breakdowns, a contract with CFE for the Electric Backup Service must be signed. In case of failures with the installed generators at the landfill, CFE automatically provides the electric power to the users. This service involves a monthly fee to CFE and serves as insurance (EPA et al., 2011).

Following the project registration to methane markets or carbon credits when biogas is captured and flared at the landfill will allow leverage benefits from national and international organisations. The landfill needs to be registered as CDM or NAMA project at the UN, the SEMARNAT and FOMECAR, which is administered by BANCOMEXT.

Necessary construction infrastructure at the landfill to flare or capture the biogas, tube it or pass it directly to the machines generating electricity, also needs to have permission.

Municipal and/or state authorisation is required for the expansion or modification of a building at the state or local government. It is likely that necessary construction equipment needs to be imported and consequently the operator must apply moreover for import permission at the Secretary of Economy (SE).

If the landfill is operated by the municipal direction or a paramunicipal company, they must follow and comply with guidelines relating to the purchase of services and products as these are treated as public entities. The guidelines of this public tender are defined in the state law commonly named Public Work Act (Ley de Obra Pública).

It is also possible that the installation of the pipes, meters, torches or electricity generating machines have to respect certain national or international regulations, for example there must be masts placed to direct the electric power. Compliance with the NOM-083 and NOM-052 needs to be constantly secured (EPA et al., 2011).

For the employees working on the landfill and in the biogas extraction process as well as for the citizens in general, more if the landfill is located in a populated area; security in the operation of the landfill must be highest priority. For this purpose, the security of the landfill needs to be approved by the state or municipal government by regular inspections. An authorisation of the equipment, technologies, procedures or alternative methods needs to be fulfilled by the Secretary of Labour and Social Welfare, especially by the General Directorate of Healt and Safety at Work (STPS) to assure the compliance with the obligations contained in the NOMs differently to those in it.

The Licence of Annual Operation (COA) is an instrument from the SEMARNAT used to monitor, report and verify (MRV) and collect information on landfill processes, pollutant release and transfer that occurred in the previous calendar year of their presentation. The monitoring and maintenance of a landfill varies whether it is operated by a municipal direction, a paramunicipal company or concession company in its legal, political and operational obligations to the municipal government according to the profile of the entity and needs regular monitoring and operational verification by a municipal supervisor. These indicators and obtained results should be defined in a manual guide.

Reaching this stage means an enormous breakthrough because the permission procedures are laborious and when they have been prosecuted and perhaps already completed, only the definite implementation action remains (EPA et al., 2011).

3.8 DISCUSSION

It appears to be the simplest and most logical solution to environmental and health problems to reduce the enormous amounts of wastes generated. Furthermore, it can be agreed that recycling strategies form a crucial component to improve the current waste management system. In Mexico, recycling initiatives appear slowly and the main obstacle is still a lack of environmental education and awareness, that, furthermore, is not prior objective of Mexican governments as financial, operational and labour resources are rather weak. The implementation of an ISWM program is very recommendable and would mean a first important step for an analysis of MSW, its management and possible improvements that could include the energetic exploitation of organic waste material. But what would bring employment for a part of the local population, on the other hand means the removal of land and occupation for the pepenadores that depend on this only possibility of garbage collection. The securing and management of such a dumpsite means the closure by covering it with plastic foil and soil and therewith the loss of many people´s livelihood, where in most cases the governments are requested to find urgent solutions. Employment for the pepenadores in a mechanical separation process could be considered, when recycling programs will be established.

To date, landfill gas capture has achieved by far the widest acceptance among technologies generating energy from MSW (EESI, 2009). Waste combustion has not

benefitted from the same public acceptance as landfill gas installations, as the emission of some pollutants could not be avoided. Gasification and plasma arc technologies still face a number of technological hurdles to commercial-scale use and only demonstration facilities have been built to date (EESI, 2009). Blue Tower and ORC are very recently discovered technologies and their implications also still need further research.
Comparing the efficiency of the presented waste to energy technologies (table 6), it can be noted that plasma arc gasification technology offers a prospering opportunity and the combustion process still shows good results due to the lower temperatures needed. Landfill diversion is measured by comparing the size of a landfill from one year to the next. This can happen through recycling, by taking used materials and creating new products, through biological treatment and processes like anaerobic digestion or thermal treatment such as incineration, combustion, gasification and so on. By applying plasma arc gasification or gasification technologies the most diversified landfill and waste sources are expected (table 5).

Efficiency of Energy Conversion Technologies [kWh/ton of waste]	
Landfill Gas Capture	41-84
Combustion	470-930
Pyrolysis	450-530
Gasification	400-650
Plasma Arc Gasification	400-1.250
Blue Tower Technology	no data
ORC Facilities	no data

Table 6: Efficiency of Energy Conversion Technologies (EESI, 2000)

Expected Landfill Diversion [%]	
Landfill Gas Capture	0
Combustion	75 (90% by volume)
Pyrolysis	72-95
Gasification	94-100
Plasma Arc Gasification	95-100
Blue Tower Technology	no data
ORC Facilities	no data

Table 5: Expected Landfill Diversion (Alt.Res.,2008; Texas Controller, 2008; EESI, 2009)

Generally, MSW still faces a number of obstacles to wider use as feedstock. Among the most important of these are local concerns about emissions, perceived competition with recycling, localisation, financing, and low federal support. Improving the status of the conditions of a landfill implies a well planned integrated strategy that needs to be formulated in a feasibility study. Run this type of project requires a long-term effort and the participation of many individuals and many public, private and social actors. It requires significant paperwork, financial costs and sometimes even higher political costs. Conducting such a project becomes the more expensive the more time passes, although financial matters are not decisive for the feasibility of a project, but should rather be under an environmental, technical and common benefit focus.
It was recommended that small, metropolitan municipalities or those with little economic possibilities consolidate their landfill to give life to a paramunicipal company, decentralised joint or inter-system company or the alike, to accumulate more residues on the landfill which means higher biogas production in the long term (EPA et al., 2011).

The support by three levels of the government (municipal, state and federal) is a must because the paperwork and permits can take month and even years to process and changes in administration or public service can become operational periods of uncertainty. The municipality, for example, is only in charge for three years and with this year´s election, strategies and priorities might shift to different topics.

As discussed throughout this document, an element that helps to facilitate, and sometimes also to complicate, the solution to that problem is the existence of a legal framework to regulate and control the generation of waste, as well as its environmentally appropriate management, depending on the suitability to local needs (Cortinas de Nava, 2001).

3.9 CONCLUSION

It has been shown that unsecured landfills represent a severe problem as in unmanaged condition they release huge amounts of methane to the atmosphere and contribute to climate change, whereas could be easily controlled with technical possibilities, adjusted with a gas socket and the generated gas be used to provide energy for the region. There are first technologies: simple power plant systems packed in a container, which can be set up in developing countries and enable small urban landfills to gain energy.

The released energy can be used 1) directly as biofuels, 2) for heating, cooking or in CHP generation or 3) in waste management facilities, where an engine is heated to produce mechanical or electrical power, a final electricity source for the end users.

Finally, as several experiences have shown, the requirements for the establishment of a waste to energy facility (Figueroa, 2007; EPA, 2009 and 2011) can be summarised in the following:

- A minimum of 2 million tons of waste production in the city
- An operation of the landfill for more than 6 years
- A pre-selection in organic and inorganic wastes
- Governmental support
- Clear property rights
- Financial investment
- Suitable equipment for efficient work
- Employment and vision for the waste collectors

The sanitation of a dumpsite for its exploitation of LFG has big potential as it furthermore can be included to international agreements for Carbon Capture and Storage or Carbon Trade like the CDM or NAMAs that can help to meet climate goals and represent a beneficial financing tool to establish facilities that achieve providing green energy for the region. Biogas generated by MSW deposited in sanitary landfills is an appropriate solution and potential energy source to meet a city´s demand for clean waste treatment and access to clean energy.

Ultimately the decisions depend on the willingness of the authorities and citizens of the municipality but it should be remembered that these also affect other communities and ultimately the release of GHGs has global dimensions.

With the intention to stimulate initiatives in this respect, the last chapter finally will respond to the research question of this thesis and showcase the biogas potential of urban organic wastes in the city of SLP.

CHAPTER 4: THE POTENTIAL BIOGAS YIELD IN SLP

4.1 INTRODUCTION

There have been few studies about the biogas potential from urban or municipal wastes in Mexico. MSWs as energy sources have been interest to scientists and governments from industrialised countries in search for a development of RE and to some extent, with the main focus on technologies from engineers for the international development cooperation. Currently existing instruments and mathematical formulas to calculate the biogas production and determine the environmental and economic benefits for the treatment of it are useful tools in this process and can provide a detailed perspective on the possibilities and requirements.

There are empirical, stoichiometric and biochemical models for predicting the methane production rate at sanitary landfills (Garg et al., 2006; Meraz et al, 2008; Chiemchaisri and Visvanathan, 2008; Aronica et al., 2009; Aguilar-Virgen et al., 2011).
Empirical equations depend on local conditions, describe the fermentation process using microbial reaction sequences such as hydrolysis, acetogenisis and methanogenisis during the anaerobic degradation process and have been used most commonly in the past years. To predict the methane production also a so called *Tier 3* method has been practised, which involves the gas extraction from one or more extraction wells in all cells and measurements of the response regarding the resulting pressure in a number of monitoring samples at different depths and distances from the extraction well (Walter, 2003). The IPCC method depends on the categories of waste, the degradable organic carbon fraction and the CH_4 content at the landfill (Chiemchaisri and Visvanathan, 2088; Machado et al., 2009). Another method is the closed-chamber flow method that estimates the gas flow based on CH_4 changes in relation to the time spent in the chamber and is measured by a camera 60 minutes after the depositing on the soil surface (Chiemchaisri and Visvanathan, 2008).

A cooperation work from EPA, COCEF and ICMA presented last year a guide for the exploitation or flaring of biogas at sanitary landfills. A calculation model was elaborated for Mexico that is explained in EPA´s Users Manual for the Mexican Biogas Model, Version 2.0 (EPA, 209). The manual describes the first activities necessary on how to operate a sanitary landfill for the landfill gas exploitation in Mexico and includes financial, legal, operational, political and social aspects and furthermore provides a checklist. This Model was already used for LFG feasibility studies in Monterrey and in Chihuahua in 2005, in Ensenada in 2009 and is applied in the present study for SLP.

4.2 METHODOLOGY

To estimate the biogas potential in SLP, MSW generation data from other Mexican cities were compared with statistical data on waste generation in SLP. Finally, the most recent available number of 302.000 tons of MSW generated in 2009 in SLP was taken for the following calculation and projection. This amount on total wastes from one year delivered to the landfill, combined with climate, geographical and operational data at the landfill, were fed into excel spreadsheets of the software of the Mexican Biogas Model Version 2.0.

Modified from the commonly used Landfill Gas Emissions Model Version 3.02 (LandGEM) and incorporating the structure of the IPCC Model, the Mexican Biogas Model 2.0 is the improved version of the first Mexican model that was developed in conjunction with the Landfill Methane Outreach Program (LMOP), SCS Engineers from the US Environmental Protection Agency (EPA), the US Agency for International Development (USAID) and several Mexican governmental agencies in 2003, with the purpose to "help landfill owners and operators and other interested parties evaluate the feasibility and potential benefits of collecting and using LFG for energy recovery in Mexico" (EPA, 2011).

The Model contains collected waste composition data from several Mexican cities and landfills to reflect local conditions and climate at disposal sites in Mexico (EPA, 2011), as well as applied advanced modelling techniques in order to provide accurate and conservative projections of LFG generation and recovery rates for the specific situation of Mexico´s landfills (EPA, 2009).

The tool bases on automatically provided input variables for the waste composition and default values for the methane generation rate (k) and the potential methane generation capacity (L_0); it considers that L_0 is related to the waste composition and the k-value, depending on many site specific parameters like moisture, temperature, oxidation, pH value, density and particle size. Site specific data inputs like the landfill location, opening and closure years, annual waste disposal rates, as well as physical and operational information about the disposal site were provided by the user´s assumptions and obtained information at the site.

Finally, the LFG potential was calculated by mathematical formula, applying a first order decay exponential equation, which assumes that the maximum biogas generation is reached after a period of time prior to the methane generation.

The applications and calculations followed the manual guide (EPA, 2009) that has been prepared specifically for Mexico as part of the M2M program activities in Mexico.

Also part of the investigation was in situ observations at the site and conversations with the authorities, operators and pepenadores to obtain information on the landfill design and operation.

4.3 INFLUENCING FACTORS FOR THE LFG GENERATION

As biogas is produced by the decomposition of wastes deposited on the landfill, the existence of low or high amount of biogas depends on several factors in situ (EPA et al., 2011):

- The amount of waste disposed per year
- The composition of the wastes including the organic waste content and moisture in the wastes
- The annual rainfall in the area

The most important factor for the production of biogas is the presence of organic material in the solid wastes. This factor is directly controlled by the volume of residential waste, as also in the volume of industrial, commercial, institutional wastes and the volume of inert material.

It was supposed that the sanitary landfill shows the following distribution of solid wastes:

- Residential volume (HSW): 60%
- Industry volume (ISW): 10%
- Dead volume: 30%

The production range (PR) would be: PR = 0.7

The sanitary landfill Peñasco is said to contain, for example, a captured waste volume of 10 million metric tons, multiplied by the PR of 0.7, this would amount 7.000.000 metric tons of waste for a potential biogas production.

10.000.000Mg x 0.7 =7.000.000Mg

The higher the PR range the higher the presence of organic material, which benefits the methanogenic bacteria´s activities and finally the biogas production.
The presence of organic material on the landfill requires a certain amount of moisture to produce the bacteria that generate biogas. Hence the rain plays an important role because it determines the humidity range.
As it has been described in chapter 2, the annual medium precipitation in SLP is 387,8mm (INEGI, 2010) which corresponds to a dry climate and the little amount of moisture in the wastes at the landfill may be a declining factor for the expected biogas potential.

Initially, residues tend to have a low pH-value so that the initial stage of the decomposition of waste is aerobic and requires oxygen from the air. Thus, the more the bacteria consume oxygen, which decomposes the waste, the pH-value rises. The optimum pH-value for the presence of methanogenic bacteria that may exist in an anaerobic environment ranges from 6,6 to 7,6 (EPA et al., 2011).

The presence of oxygen in the waste mass accelerates the aerobic decomposition of the organic material and an oxygen decline accelerates the anaerobic decomposition due to physical and chemical conditions that allow the existence of methanogenic bacteria to produce biogas. An anaerobic process occurs in a range of 0°C to 69°C, but the biogas production activity declines rapidly when the temperature drops to 20°C and is more active in a temperature range between 29°C and 41°C. The optimal temperature range is considered between 32°C and 35°C. When the temperature exceeds 60°C the biogas production will reduce (EPA et al., 2011).

Production Range	Low	Medium	High
	0,1 – 0,3	0,4 - 0,6	0,7 - 1,0
Annual Rainfall	Dry	Semi-humid	Humid
	<500mm/y	500mm/y – 1000mm/y	>1000mm/y
Oxygen Range	Low	Medium	Optimum
	25-15%	14 - 4%	>3%
Temperature Range	Low	Efficient	Low
	<20°C	32 - 25°C	>60°C

Table 7: Optimum Ranges for Influencing Factors for the Biogas Generation (EPA et al., 2011)

There are other vital factors that influence the calculation of the biogas production, such as the amount of waste deposited, the age of the wastes, the amount expected to be buried during the operation of the landfill and also how many years it will be receiving solid wastes.

The Mexican LFG Model uses the following information to estimate the generation and recovery of biogas in a landfill:

- The annual amount of wastes deposited at the landfill
- The year of opening and closing of the site
- The methane generation rate constant (k) [year -1]
- The potential methane generation capacity(L_0) [$m^3 CH_4$/Mg of MSW]
- The methane correction factor (MCF)
- The fire adjustment factor (F)
- The recovery efficiency of the capture system

This method estimates the biogas generation rate for each year by applying the equation of the degradation of the first degree and using cumulative quantities of wastes disposed throughout one year (EPA, 2011), based on the following formula:

$$Q_{LFG} = \sum_{t=1}^{n} \sum_{j=0.1}^{1} 2kL_0 \left[\frac{M_i}{10} \right] (e^{-kt_{ij}}) \, (MCF) \, (F)$$

Where:
Q_{LFG} = Maximum expected LFG flow rate [m^3/ year]
i = 1 year time increment
n = (year of the calculation) - (initial year of waste disposal)
j = 0,1 year time increment
k = Methane generation rate constant [1/year]
L_0 = Potential methane generation capacity [m^3/Mg]
M_i = Mass of solid waste disposed in the i^{th} year [Mg]
t_{ij} = Age of the j^{th} section of waste mass M_i disposed in year i (decimal years)
MCF = Methane correction factor
F = Fire adjustment factor

4.4 WASTE DISPOSAL

The first input to the Mexican LFG Model is the location of the landfill. The Model takes given climate data per regions in which Mexico is categorised. SLP responds to the region 5, Northeast and Interior North.

Secondly, the annual waste generation amount in metric tons [Mg] for the site is required. When there is no data available, the Model automatically calculates with estimate disposal data, including future years. The disposal estimates should be consistent with site specific data on amounts of waste at the place, the total site capacity and the projected closure year. In SLP, the most recent official annual disposal figure was from 2009, which were 302.000 tons of MSW deposited at Peñasco (INEGI, 2010). The sanitary landfill began operating in 1995, was sanitised in 2009 and is planned to be object to biogas extraction for the upcoming years. For the present calculation the closure year and start of biogas extraction was projected for 2013.

The user can specify the waste composition in an extra sheet when there is data at hand; otherwise the Model automatically assigns typical average waste composition data for the selected state, using the population number to weight the contribution of each data set to the average. As it was not possible to obtain detailed information on the waste composition in SLP the given data in the first column from figure 21 was used and can directly be compared to the waste composition of other Mexican cities where a potential LFG recovery was calculated.

The Model applies separate equations to calculate the LFG generation from each of the following four organic waste categories:

1. Very fast decaying waste (FDW): food waste, other organics, 20% of diapers
2. Medium fast decaying waste (MFDW): garden waste, toilet paper
3. Medium slow decaying waste (MSDW): paper and cardboard, textiles
4. Slowly decaying waste (SDW): wood, rubber, leather, bones, straw

Methane to Markets

Mexico Landfill Gas Model v.2

Release Date: March 2009

Developed by SCS Engineers for the U.S. EPA Landfill Methane Outreach Program

PROJECTION OF LANDFILL GAS GENERATION AND RECOVERY

INPUT WORKSHEET

1	Landfill name:	Peñasco	
2	City:	San Luis Potosí	
3	State:	San Luis Potosi	
4	Region:	Northwest & Interior North	5
5	Site-specific waste composition data?	No	
6	Year opened:	1995	
7	Annual disposal in 2008 or most recent year:	302.000	Mg
8	Year of disposal estimate:	2009	
9	Projected or actual closure year:	2013	
10	Estimated growth in annual disposal:	2,0%	
11	Average landfill depth:	12	m
12	Site design and management practices:	2	
13a	Has site been impacted by fires?	Yes	
13b	If 13a answer is Yes, indicate % of landfill area impacted:	30%	
13c	If 13a answer is Yes, indicate the severity of fire impacts:	1	
14	Year of initial collection system start-up:	2013	
15	Percent of waste area with wells:	70%	
16	Percent of waste area with final cover:	60%	
17	Percent of waste area with intermediate cover:	0%	
18	Percent of waste area with daily cover:	30%	
19	Percent of waste area with no soil cover:	10%	
20	Percent of waste area with clay or synthetic liner:	50%	
21	Is waste compacted on a regular basis?	No	
22	Is waste delivered to a focused tipping area?	Yes	
23a	Does the landfill experience leachate surface seeps or surface ponding?	Yes	
23b	If 23a answer is yes, does this occur only after rainstorms?	No	
24	Collection efficiency estimate:	49%	

Figure 21: Input Sheet

Methane to Markets

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SITE-SPECIFIC AND DEFAULT WASTE COMPOSITION TABLE FOR MODEL INPUTS

Waste Category	San Luis Potosi	San Luis Potosi	Queretaro	Chihuahua	Baja California North
Food Waste	38,3%	30,7%	29,9%	26,0%	35,8%
Paper and Cardboard	10,4%	16,3%	17,5%	18,5%	13,1%
Garden Waste (Green Waste)	13,2%	9,9%	4,3%	7,1%	15,5%
Wood Waste	0,2%	1,1%	1,0%	1,0%	0,5%
Rubber, Leather, Bones, Straw	1,2%	1,2%	1,7%	1,2%	0,7%
Textiles	4,9%	5,4%	2,8%	7,4%	4,1%
Toilet Paper	0,0%				
Other Organics	4,9%	1,9%	4,3%	1,8%	1,6%
Diapers (assume 20% organics / 80% inorganics)	5,1%	6,4%	4,3%	4,9%	11,9%
Metals	21,8%		2,5%	3,2%	3,2%
Construction and Demolition Waste	0,0%		1,5%	2,0%	0,0%
Glass and Ceramics	0,0%	26,9%	4,3%	4,1%	3,5%
Plastics	0,0%		19,2%	16,2%	7,5%
Other Inorganic Waste (bulky items)	0,0%		6,7%	6,6%	2,7%
Percent very fast decay organic waste (1)	44,2%	34,0%	35,1%	28,8%	39,7%
Percent medium-fast decay organic waste (2)	13,2%	9,9%	4,3%	7,1%	15,5%
Percent medium-slow decay organic waste (3)	15,3%	21,7%	20,3%	25,8%	17,2%
Percent slow decay organic waste (4)	1,4%	2,2%	2,7%	2,2%	1,2%
Total Organic Waste	74,2%	67,9%	62,4%	63,9%	73,5%
Total Inorganic Waste	25,8%	32,1%	37,6%	36,1%	26,5%
Average very fast decay organic waste moisture (1)	70%	70%	70%	70%	70%
rage medium-fast decay organic waste moisture (2)	50%	35%	40%	35%	35%
age medium-slow decay organic waste moisture (3)	7%	7%	7%	7%	7%
Average slow decay organic waste moisture (4)	12%	12%	12%	12%	12%
U.S. Waste - % dry organics					
Calculated Fast-decay Organic Waste Lo	69	69	69	69	69
Calculated medium fast decay Organic Waste Lo	115	149	138	149	149
Calculated medium slow decay Organic Waste Lo	214	214	214	214	214
Calculated Slow-decay Organic Waste Lo	202	202	202	202	202

Figure 22: Site Specific Waste Composition Model Inputs

4.5 DETERMINATION OF K AND L_0

The potential LFG recovery bases on two fundamental parameters:
k = methane generation rate constant [year -1]
L_0 = potential methane generation capacity [m^3CH_4/Mg of MSW]

According to their level of degradation from the information about the waste composition, the tool automatically assigns values for k and L_0.

The k-value determines the rate of methane generation from the refuse at the landfill. The unit for k is in year -1. It describes the rate at which refuse is placed at the disposal site, decays and produces methane and is related to the half-life of wastes according to the equation: half-life = In (2)/k. The higher the k-value, the faster the total methane generation at a landfill increases and then declines over time after the landfill closes.

The value for the potential methane generation capacity (L_0) of a refuse describes the total amount of methane gas potentially produced by a ton of refuse as it decays and also depends on the waste composition at the landfill. Here, the higher the cellulose content, the higher the L_0-value. The units of L_0 are in cubic meters per ton of refuse. The values of theoretical and obtainable L_0 range from 6.2 to 270m^3/Mg refuse (EPA, 1991 in EPA, 2009).

For region 5 the following k and L_0-values were assigned, depending on the waste category (table 9) as shown earlier.

Region 5: Northeast and Interior North of Mexico		
Waste Category	k- value	L_0-value [m^3CH_4/Mg]
1	0,100	69
2	0,050	149
3	0,020	214
4	0,010	202

Table 9: k and L_0 value for region 5

Waste Composition for San Luis Potosí			
Waste Category	Waste Share [%]	Moisture [%]	L_0 –value [m^3CH_4/Mg]
1	44,2	70	69
2	13,2	50	115
3	15,3	7	214
4	1,4	12	202

Table 8: Waste Composition for SLP

The difference in the L_0-value for the wastes in SLP is because of the moisture percentage for waste category 2, which are medium fast decaying wastes, including garden waste and toilet paper. The moisture content was estimated on 50% and thus has implications for the potential methane generation on the landfill.

Finally, for SLP, the k-value was determined 0,100 FDW; 0,050 MFDW; 0,020 MSDW and 0,010 SDW and the results for L_0 [m^2/Mg] were 62 FDW; 103 MFDW; 192 MSDW and 182 SDW (figure 23). These differences are due to adjustments that have been made and will be explained subsequently.

MODEL INPUT PARAMETERS
Assumed Methane Content of LFG: 50%
Methane Correction Factor (MCF): 1,0

Waste Category:	Fast Decay	Moderately Fast Decay	Moderately Slow Decay	Slow Decay
CH4 Generation Rate Constant (k):	0,100	0,050	0,020	0,010
CH4 Generation Potential (Lo) (m3/M	62	103	192	182

Figure 23: k and L_0 values for SLP with MCF

The k-value is in function of:

- Refuse moisture content
- Availability of nutrients for methane-producing bacteria
- pH-value
- Temperature

Moisture conditions inside a landfill are typically not very well known and therefore estimated by the average annual precipitation at the site. The nutrients availability depends on waste amounts and their composition. The pH-value is unknown and not evaluated in this model. The temperature on a landfill is kept relatively constant by the anaerobic bacteria´s activity and is mostly not influenced by outside temperatures, unless it is very cold climate. Basically, the k-value only takes into consideration the waste composition and climate data.

The L_0-value, in fact, includes an adjustment to account for aerobic waste decay known as the methane correction factor (MDF) and an adjustment to account the fire risk (F). The MCF is a correction to the Model´s estimates about the LFG generation potential that accounts for the degree to which wastes decay aerobically and varies depending on the waste depth, landfill type and management practices. At managed landfills or dumpsites that have conditions less conductive to anaerobic decay, the MDF will be lower to reflect the extent of aerobic conditions at these sites (EPA, 2009).

Site management	Depth <5m	Depth >= 5m
Unmanaged disposal site	0,4	0,8
Managed landfill	0,8	1,0
Semi-aerobic landfill	0,4	0,5
unknown	0,4	0,8

Table 10: Disposal Site Management Categories

A managed landfill here is defined as having a controlled placement of the wastes, which means that wastes are directed to a specific determined area and a certain degree of scavenging and separation occurs, the wastes are mechanically compacted or levelled or there is a certain cover material placed (IPCC, 2006). A semi-aerobic landfill is understood as a site where waste placement and air infiltration to the wastes is controlled by e.g. permeable cover material, a leachate drainage system and a gas ventilation system (IPCC, 2006).

The site design and management practises at Peñasco in SLP were categorised with 2, an engineered managed sanitary landfill (table 10). The average depth of each cell was estimated at 12m as the maximum depth measured and reported was 22m of waste accumulated at Peñasco. This is more than 5 meter and results in a MCF of 1,0 that was applied to L_0.

Also the fire risk factor (F) can reduce the LFG generation potential as landfill fires consume waste as a fuel and leave behind ash that does not produce gas and thus landfills impacted by fires in history need to address this value. Peñasco, which was operating from 1995 to 2009 under unmanaged conditions, has been impacted by fires in some occasions. The Model discounts the LFG generation by the percentage of the

landfill area that has been impacted, multiplied by an adjustment for the severity of the impacts (1/3 for low impacts, 2/3 for medium impacts and 1 for severe impacts).
The dimensions of the fire impacts at Peñasco were estimated to be low and specified to have impacted 30% of the area.

4.6 THE COLLECTION EFFICIENCY

The LFG recovery will be estimated by the Model by multiplying the projected LFG generation with the estimated collection efficiency.

The collection efficiency factor is calculated automatically on the initial waste amount that will be reduced by taking into account the following factors:

- Collection system coverage
- Waste depth
- Cover type and extent (e.g. permeable soil cover)
- Landfill liner (clay or synthetic)
- Waste compaction
- Size of the active disposal
- Leachate management

These factors directly determine the limits of LFG release to the atmosphere, air and water infiltration and thus influence significantly the collection efficiency of the system.
The collection system coverage describes the percentage of the landfill area where wells are installed. The area at Peñasco equipped with wells was estimated to be 70%. When the system is already in operation it should also include discounts for non-functioning wells and of course, also the well depth and number of wells on the landfill influence this factor.

In the present calculation (figure 24), the discount starts with 70% representing the landfill area covered with wells, because the waste depth at Peñasco is more than 10m. Otherwise, the Model would assume a 5% discount for every 1m of waste depth less than 10m to the estimated collection efficiency (EPA, 2009).

	Collection Efficiency Calculation	
Account for waste depth:	100%	Progressive discount if <10 m deep (5% for each meter < 10m)
Account for wellfield coverage of waste area:	70%	Coverage factor adjustment
Account for soil cover type and extent:	57%	Final cover = 90%; intermediate cover = 80%; daily cover = 75%; no cover = 50%
Account for liner type and extent:	56%	Discount is 5% x % area without liner
Account for waste compaction:	54%	Discount is 3% if no compaction
Account for focused tip area:	54%	Discount is 5% if no focused tip area
Account for leachate	49%	Discount is up to 40% depending on climate and frequency of leachate ponding/runoff
CALCULATED COLLECTION EFFICIENCY:	**49%**	

Figure 24: Collection Efficiency Calculation

The factor for the soil cover type and extent reduces the collection efficiency by 13%. Little soil cover will favour LFG emissions to the atmosphere as well as air and water infiltration that causes leachate levels to build up and block the gas collection. These effects depend on the size of the area with cover, its permeability and thickness.

At Peñasco only two cells currently receive wastes that have been separated by the pepenadores prior to the final depositing and waste picking is still permitted to some pepenadores at these cells. Discarded wastes remain at the cell until their final closure. All the other cells have been closed so far with final covering.
Intermediate soil cover installed over areas that have not yet been used for disposal for an extended period, allow moderate control over air and rainfall infiltration and gas emissions. These could not be identified at Peñasco. Daily soil cover typically is a shallower layer of soil that is installed at the end of the day in active disposal areas and provides a more permeable layer to air and water than final or intermediate cover soils. The Model will apply 90% collection efficiency in percentage to the landfill area with final cover, 80% for intermediate cover, 75% for daily cover and 50% for areas with no soil cover. The final cover at Peñasco was determined on 60%, intermediate cover on 0%, daily cover 30% and a remaining open waste picking area with no cover of 10%.

If the landfill does not count with clay, synthetic, geomembrane or other bottom liner material that act as low-permeability barrier, a discount to the collection efficiency equal to 5% times the percentage of the area will be applied. The cells at Peñasco are prepared with synthetic liner and are covered with soil from the surrounding area. For the calculation, the area of cells with final cover and liner was estimated to be 50%.

If trucks unload the wastes in a specific area at the disposal site where they would be compacted, a certain waste depth could be achieved and if the soil is covered regularly, this will improve the system´s efficiency. Peñasco does not count with a regular waste compaction installation and thus the efficiency needs to be discounted by 3%.
The collection efficiency would further be discounted by 5% if the wastes are not delivered to a focus tipping area. This is the case for Peñasco, where valuable resource wastes are firstly separated and selected by pepenadores.

Thus, the LFG collection efficiency will only further be reduced by the account for leachate. Leachate almost always limits effective collection system operation at landfills in developing countries because of the high moisture content and often improper drainage system (EPA et al., 2011). High leachate levels can block the well perforations and prevent those from applying vacuum to draw in LFG from the surrounding waste mass and the landfills will often show signs of liquid accumulation through surface seeps or ponding. If this occurs only after heavy rainstorms the model will decrease the efficiency by 2-15%, but if it persists, 10 to 40% discount will be applied, depending on the climate (EPA, 2009). At the cells of the Peñasco landfill, leachate was observed to some extent and does not occur only after rainstorms.

The ability of the gas collection system to capture the generated LFG is a function of the system´s design, operation and maintenance. All these factors influence the collection efficiency. If it involves a discount, a value of one minus the discount will be used in the calculation. These factors finally results in overall system efficiency at Peñasco of 49%.

This collection efficiency is the percentage that estimates the amount of LFG that can be recovered for flaring or beneficial energetic utilisation and unless there is no actual LFG recovery data available, it is not recommended to make adjustments to the collection efficiency factor.

4.7 LFG GENERATION AND RECOVERY

The worksheet about the disposal and LFG recovery provides the opportunity to enter annual disposal rates for years in which waste disposal data is available.
When the system is already operating, also actual LFG recovery rates and baseline LFG recovery can be specified.

The waste disposal estimates in metric tons [Mg] for each year will be accumulated according to the estimated growth in annual waste disposal.
In 2009, a total MSW of 302.000 tons were deposited at Peñasco. Given a growth rate of 0,2% for the generation of wastes in SLP, the Model estimates an amount of 228.900 Mg deposited in 1995, the year the landfill started operating, that would have reached a cumulative amount of 3.961.600Mg by 2009.

The Model projects a disposal of 326.900 tons of wastes in the year 2013, which would reach an accumulation of 5.231.200 tons of waste at the landfill by 2013, the year when the system would start to exploit the generated LFG. Given the system collection efficiency of 49%, the potential LFG recovery is projected to be 1,237m^3/hr at a methane rate of 50% (figure 25). After a supposed closure in 2013, the LFG recovery rate would decline (figure 26).

Mexico Landfill Gas Model v.2

Release Date: March 2009

Methane to Markets Developed by SCS Engineers for the U.S. EPA Landfill Methane Outreach Program

DISPOSAL AND LFG RECOVERY WORKSHEET

Year	Waste Disposal Estimates (Metric Tonnes)	Cumulative Metric Tonnes	Collection System Efficiency	Actual LFG Recovery (m3/hr at 50% CH4)	Projected LFG Recovery (m3/hr at 50% CH4)	Baseline LFG Recovery (m3/hr at 50% CH4)
1995	228.900	228.900	0%		0	0
1996	233.500	462.400	0%		0	0
1997	238.200	700.600	0%		0	0
1998	243.000	943.600	0%		0	0
1999	247.900	1.191.500	0%		0	0
2000	252.900	1.444.400	0%		0	0
2001	258.000	1.702.400	0%		0	0
2002	263.200	1.965.600	0%		0	0
2003	268.500	2.234.100	0%		0	0
2004	273.900	2.508.000	0%		0	0
2005	279.400	2.787.400	0%		0	0
2006	285.000	3.072.400	0%		0	0
2007	290.700	3.363.100	0%		0	0
2008	296.500	3.659.600	0%		0	0
2009	302.000	3.961.600	0%		0	0
2010	308.000	4.269.600	0%		0	0
2011	314.200	4.583.800	0%		0	0
2012	320.500	4.904.300	0%		0	0
2013	326.900	5.231.200	49%		1.237	0

Figure 25: Disposal and LFG Recovery in SLP

2012	320.500	4.904.300	0%		0	0
2013	326.900	5.231.200	49%		1.237	0
2014	0	5.231.200	49%		1.290	0
2015	0	5.231.200	49%		1.203	0
2016	0	5.231.200	49%		1.122	0
2017	0	5.231.200	49%		1.048	0
2018	0	5.231.200	49%		981	0
2019	0	5.231.200	49%		918	0
2020	0	5.231.200	49%		861	0
2021	0	5.231.200	49%		808	0
2022	0	5.231.200	49%		760	0
2023	0	5.231.200	49%		715	0
2024	0	5.231.200	49%		674	0

Figure 26: LFG Recovery after closure

Methane to Markets

Mexico Landfill Gas Model v.2

Release Date: March 2009

Developed by SCS Engineers for the U.S. EPA Landfill Methane Outreach Program

PROJECTION OF LANDFILL GAS GENERATION AND RECOVERY
Peñasco
San Luis Potosí, San Luis Potosi

Year	Disposal (Mg/yr)	Refuse In-Place (Mg)	LFG Generation			Collection System Efficiency (%)	Predicted LFG Recovery			Maximum Power Plant Capacity* (MW)	Baseline LFG Flow (m3/hr)	Methane Emissions Reduction Estimates**	
			(m^3/hr)	(cfm)	(mmBtu/hr)		(m^3/hr)	(cfm)	(mmBtu/hr)			(tonnes CH_4/yr)	(tonnes CO_2eq/yr)
1995	228.900	228.900	0	0	0,0	0%	0	0	0,0	0,0	0	0	0
1996	233.500	462.400	197	116	3,5	0%	0	0	0,0	0,0	0	0	0
1997	238.200	700.600	382	225	6,8	0%	0	0	0,0	0,0	0	0	0
1998	243.000	943.600	558	329	10,0	0%	0	0	0,0	0,0	0	0	0
1999	247.900	1.191.500	726	427	13,0	0%	0	0	0,0	0,0	0	0	0
2000	252.900	1.444.400	885	521	15,8	0%	0	0	0,0	0,0	0	0	0
2001	258.000	1.702.400	1.038	611	18,5	0%	0	0	0,0	0,0	0	0	0
2002	263.200	1.965.600	1.184	697	21,2	0%	0	0	0,0	0,0	0	0	0
2003	268.500	2.234.100	1.324	779	23,7	0%	0	0	0,0	0,0	0	0	0
2004	273.900	2.508.000	1.459	859	26,1	0%	0	0	0,0	0,0	0	0	0
2005	279.400	2.787.400	1.590	936	28,4	0%	0	0	0,0	0,0	0	0	0
2006	285.000	3.072.400	1.717	1.011	30,7	0%	0	0	0,0	0,0	0	0	0
2007	290.700	3.363.100	1.840	1.083	32,9	0%	0	0	0,0	0,0	0	0	0
2008	296.500	3.659.600	1.961	1.154	35,0	0%	0	0	0,0	0,0	0	0	0
2009	302.000	3.961.600	2.078	1.223	37,1	0%	0	0	0,0	0,0	0	0	0
2010	308.000	4.269.600	2.193	1.291	39,2	0%	0	0	0,0	0,0	0	0	0
2011	314.200	4.583.800	2.305	1.357	41,2	0%	0	0	0,0	0,0	0	0	0
2012	320.500	4.904.300	2.416	1.422	43,2	0%	0	0	0,0	0,0	0	0	0
2013	326.900	5.231.200	2.525	1.486	45,1	49%	1.237	728	22,1	2,0	0	3.881	81.491
2014	0	5.231.200	2.633	1.550	47,1	49%	1.290	759	23,1	2,1	0	4.047	84.979
2015	0	5.231.200	2.454	1.444	43,9	49%	1.203	708	21,5	2,0	0	3.771	79.197
2016	0	5.231.200	2.290	1.348	40,9	49%	1.122	660	20,1	1,9	0	3.519	73.897
2017	0	5.231.200	2.139	1.259	38,2	49%	1.048	617	18,7	1,7	0	3.287	69.036
2018	0	5.231.200	2.001	1.178	35,8	49%	981	577	17,5	1,6	0	3.075	64.575
2019	0	5.231.200	1.874	1.103	33,5	49%	918	540	16,4	1,5	0	2.880	60.477
2020	0	5.231.200	1.757	1.034	31,4	49%	861	507	15,4	1,4	0	2.700	56.710
2021	0	5.231.200	1.650	971	29,5	49%	808	476	14,4	1,3	0	2.536	53.246
2022	0	5.231.200	1.551	913	27,7	49%	760	447	13,6	1,3	0	2.384	50.056
2023	0	5.231.200	1.460	859	26,1	49%	715	421	12,8	1,2	0	2.244	47.117
2024	0	5.231.200	1.376	810	24,6	49%	674	397	12,0	1,1	0	2.115	44.407

Figure 27: LFG Generation and Recovery in SLP

The Model displays the results in an output table worksheet (figure 27) and a graph (figure 28). The output table bases on the inputs from the disposal and LFG recovery worksheet and calculates the following factors:

- Start and ending of the landfill operation in years
- Annual disposal rates in Mg per year
- Refuse in place in Mg
- LFG generation for each projection year in m^3/hr, cfm and mmBtu/hr
- Collection system efficiency estimates for each projection year
- LFG recovery rates for each projection year in m^2/hr, cfm and mmBtus/hr
- Maximum power plant capacity that could be supported by this flow in MW
- Baseline LFG flow in m^3/hr
- Methane emission reduction (CERs) estimates in tons of CH_4/year and in tons of CO_2e/year
- Methane content assumed for the model projection (50%)
- K values used for the model run
- L_0 values used for the model run

In the presented calculation, a LFG generation of 2,525m^3/hr with a LFG recovery potential of 1,237m^3/hr could be achieved for 2013, representing 2,1MW potential power plant capacity. The maximum power plant capacity assumes a gross heat rate of 10,800 Btus/kWh (hhv).

As the programme suggests, the LFG generation at the sanitary landfill Peñasco would reach its peak at 2,633 m^3/hr one year after the closure, which is projected for 2013 and estimates a LFG recovery of 1,290m^3/hr and 2,1MW maximum power plant capacity in 2014. After the closure the LFG generation declines.

For already operating LFG collection systems, the actual LFG recovery data need to be converted to m^3/hr, adjusted to 50% methane equivalent and averaged. The calculated average LFG recovery rate should be the average annual total LFG flow at the flare station.

Additionally, the baseline LFG recovery estimates are subtracted from the projected LFG recovery to estimate Certified Emission Reductions (CERs). For estimating the baseline LFG recovery the most recent CDM methodologies should be consulted.
The Model calculated emission reductions of 3,881 tons of CH_4 per year and 81,491 tons of CO_2 equivalents per year for 2013.
Emission reductions do not account for the electricity generation or project emissions and are calculated using a methane density, at standard temperatures and pressure, of 0.0007168Mg/m^3 (EPA, 2009).

Results on LFG generation rates for each projection year in m^3/hr, LFG recovery rates for each projection year in m^3/hr and the actual (historical) LFG recovery rates in m^3/hr, if available, are furthermore displayed in graphical form (figure 28).

The landfill started receiving wastes in 1995 and the deposited wastes accumulated during these years started generating LFG, which reaches its peak in 2014 at 2,633 m^3 per hour, after the projected closure in 2013. The LFG recovery is presented from 2013 on, when the collection system starts and reaches in 2014 an amount of 1,290 m^3 per hour. When the landfill stops receiving wastes in 2013 both factors decline.

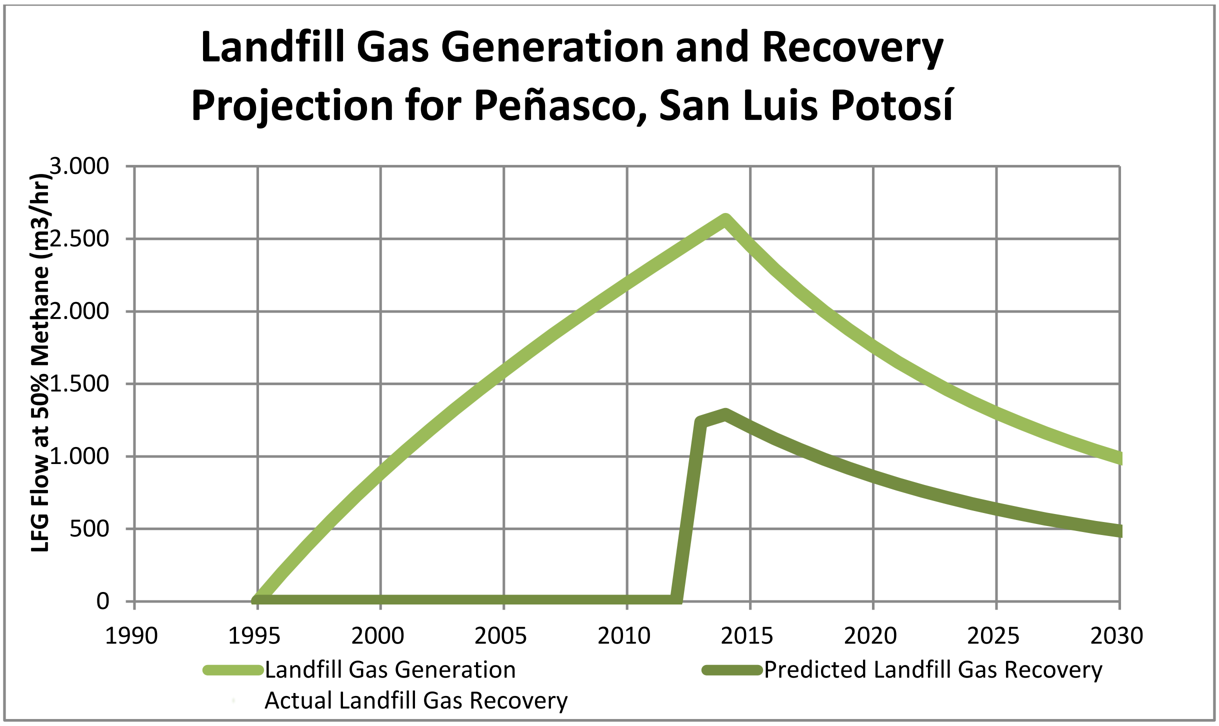

Figure 28: LFG Generation and Recovery Projection for Peñasco, SLP

4.8 DISCUSSION

The first step for future proposals on how to integrate waste for a productive energetic use is determining the potential biogas yields that could be expected from the MSW generation at the landfill Peñasco in SLP. This approach reflects a theoretical calculation that bases on many assumptions, rough estimations and projections.

The Mexican LFG Model 2.0 is a useful tool that is easily applicable, especially when there is no concrete data on waste disposal rates, waste composition etc.
However, because the Model bases on very site specific factors that determine the overall collection efficiency, in situ studies are necessary.

Evaluating these factors requires a well knowledge and familiarity with the landfill´s design and operation. For example, the Model requires only a percentage of the landfill area covered with wells but gives no room for further detailed information.
Information about well spacing and depth is important. Wells deeper than 20 meters can collect more LFG from all areas on the landfill as more vacuum can be applied, whereas shallower wells than 10m will tend to have greater air filtration and will require more than two wells per hectare to achieve the same efficiency. Landfills with a dense network of wells will collect more total gas than landfills with more widely spaced wells and landfills with a small number of well-spaced wells typically collect more gas per well (SCS Engineers, 2005; EPA, 2009).

Also, it was recognised that unmanaged disposal sites with little or no soil cover have high rates of gas emissions and air infiltration, resulting in lower rates of LFG capture. Areas without a soil cover will have high rates of rainfall infiltration causing leachate that may block the gas collection system with liquids (EPA, 2009). These are essential information that may directly change the overall collection efficiency, on what the final LFG recovery depends on. Slight uncertainties about the respective soil cover percentages will have great implications on the final result.

It was noticed that the accuracy of these estimations tend to be higher when the collection efficiency results high and lower when it is low. Underestimations have been experienced although the model is intended to be used by non-professionals who are not trained in methods for evaluating collection efficiency.
If there is available information, for example, when the system is already in operation or there has been conducted a feasibility study at the landfill, it is recommendable to adjust these factors when possible.
Reasonable collection efficiencies for landfills in the USA had an average of 75% (EPA, 2012). The IPCC (2006) report stated that ">90% recovery can be achieved at cells with final cover and an efficient gas extraction system." It is said that modern Mexican sanitary landfills can reach a maximum collection efficiency of more than 90% under best conditions, while unmanaged disposal sites may never exceed 50% collection efficiency even with a comprehensive system (SCS Engineers, 2005).
Most landfills in Mexico will have considerably less than 100% collection system coverage due to the large number of uncontrolled waste pickers in unsecured areas.

A crucial point that needs to be discussed are the many uncertainties the presented calculation faced. Beginning with the total waste disposal for one year, it was formerly explained in chapter 2 that it was very difficult to obtain official data on the waste generation for SLP. The analysis on waste generation showed a general per capita HSW generation of 0,9kg per person per day for Mexico. The waste generation for metropolitan zones per capita was estimated to be even 1,5kg. Calculating with current 772.604 inhabitants for the municipality of SLP this would amount to 1.158,906 tons per day and 423.000,690 tons in a year.

The official figure of 302.000 tons of MSW deposited at Peñasco that was provided in 2009 was used as base input for the waste disposal rate in this calculation. It was estimated that the annual disposal growth rate was 2,0%, which resulted in a total accumulated amount of 3.961.6000Mg of wastes for 2009. When Peñasco was sanitised in 2009, the total amount there was estimated to be more than 10 million tons. These figures are likely to be overestimations as they are most probably based on the impressive maximum height of 22m wastes that, however, do not exist constantly.
Even when we consider that there were more wastes deposited in the last years. For example, 900 tons per day (Govea, 2012 pers. com.) during the last 18 years, this would only amount to a total of 5.913.000 tons as by 2013. This figure in fact, is closer to the calculated amount of 5.231.200 Mg the Model provides.

Generally, it cannot be excluded that the presented information and data are under- or overestimations and may contain errors and inaccuracies. It can be argued that the presented information do not derive from own waste analysis and do not reflect the waste generation of SLP and the actual biogas generation at the landfill. Measuring the present influencing factors would need to be calculated professionally.

However, when compared to other Mexican cities where the Model was tested, the results for Peñasco in SLP agree with the experiences in Ensenada, Chihuahua and Queretaro. Figure 22 was composed to provide a direct comparison of the waste composition in Mexican cities. These results again show that the organic components of MSW are more than 50% and similar to what was reported for mid-sized Mexican cities:

- Mexicali 64,78%
- Chihuahua 62,00%
- Guadalajara 63,50%
- Morelia 68,10%
- Ensenada 68,57%

A study in 2009 from Aguilar-Virgen et al. (2011) in Ensenada, Northern Baja California, that has a rather mild climate, estimated the biogas potential using the Mexican biogas model that was supported by a waste characterisation study. It was suggested that a high content of organic material (68%) might be responsible for a relatively high biogas potential that can be used for the local energy production.
The landfill in Ensenada also calculated with a daily per capita rate of 0,9 waste generated and 68% organic matter. An operation time from 2004 to 2018, an average of 15m cell depth, a disposal amount of 132.055Mg from the most recent data of 2005 and 75% waste compaction resulted in 1,152 m^3/hr LFG recovery and 1,90MW maximal capacity for 2018. These results are similar to the presented calculation for SLP.
The case of Ensenada has shown that the electricity generated from the landfill could provide 3,46% of the city´s installed electricity generation capacity in 2004, cover 60% of the public lighting and approximately 1.423 million US$ would be saved. The

emissions reduced would account for around 747.060Mg during 2009 and 2022 and be worth 8,2 million US$ on the carbon market (Aguilar-Virgen et al, 2011).

Another study conducted in 2005 at the Chihuahua sanitary landfill using the same model and a mid-range scenario estimated the maximum electric power generation to be 3,30 MW in 2009. In Chihuahua the total waste input was calculated with 230.000 Mg annually and 68% organic composition. The landfill started in 1994 and will close in 2013. In Queretaro the biogas recovery was estimated at 3,20 MW for 2009 with an annual amount of 300.000 Mg MSW, 62% organic matter and an operation time from 1996 until 2015 (SCA Engineers, 2005a, 2005b and 2005c; Aguilar-Virgen et al., 2011).

These differences are most likely to be due to waste composition differences, because for the Queretaro study typical US proportions were used and these percentages affect the k and L_0-values. A study of the SIMEPRODE sanitary landfill in Monterrey from BENLESA used a different methodology and model and cannot be compared to these results shown. Criteria must be standardised to be able to make valid comparisons between Mexican landfills and their biogas recovery potential.

4.9 CONCLUSION

Landfills represent the third largest source of anthropogenic methane emissions worldwide, constituting around 13% to global methane emissions (Zhang et al, 2008; Kumar et al., 2004) and being 21 times more harmful than CO_2 due to its stronger molar absorption coefficient regarding infrared radiation and longer residence time in the atmosphere (Batool and Chuadhry, 2008; Christophersen et al., 2001). The longer time wastes are deposited at uncontrolled landfills, the produced biogas or LFG will be emitted as dangerous GHGs rather than to provide energy.

The generation of LFG is influenced by the physical-chemical composition of the wastes and other environmental factors like the type of waste and total amount of organic matter disposed, age, temperature, moisture content, particle size and nutrients, soil cover, compaction techniques used at the landfill and so on (Kumar et al., 2004; Kong, 2008; EPA, 2009; Aguilar-Virgen et al., 2011; EPA, 2011). The optimal conditions for the methane production are an organic material content higher than 60%, a moisture content of 50-60%, 40°C temperature, a neutral pH-value, small particle size, well compacted waste and other conditions that prevent oxygen infiltration (Kong, 2008; EPA, 2009; EPA, 2011).

For the sanitary landfill Peñasco in San Luis Potosí, that started operating in 1995, the LFG recovery was projected for 2013. The waste disposal rate is provided by the latest official figure of 302.000 tons of MSW deposited at the landfill in 2009. According to an estimated annual disposal growth rate of 2,0%, the wastes at Peñasco would have

accumulated to a total amount of 5.231.200Mg by 2013, having a share of 74,2% of organic wastes. The system would reach its peak one year after the closure in 2014, projecting a LFG generation of 2.633m^3/hr. It was estimated that, based on a system collection efficiency of 49% and methane content of 50%, 1.290m^3/hr of LFG could be recovered to provide a maximal power plant capacity of 2,1MW in 2014.
This could mean Certified Emission Reductions of 4,047tCH_4 and 84,979tCO_2eq for 2014.

The presented calculations base on a theoretical tool, the Mexican LFG Model Version 2.0, and again, it has to be recognised that information regarding the waste generation and composition in situ is of crucial importance to provide an accurate figure of the potential biogas.

The next necessary step would be conducting a practical feasibility study for the city of SLP, using the presented Model to identify similarities to other studies and create background information in order to promote waste to energy strategies for achieving sustainable development.

GENERAL CONCLUSION

Mexico, a main oil producing country, is largely dependent on oil for the energy mix (35%). Electrical power is generated mostly by hydraulic and thermoelectric sources and renewable energies have a share of less than 1% to the Mexican electricity generation (SIE-BNE, 2010). Mexico proposed a law on the exploitation of renewable energy sources (LAFRE) that has the goal to achieve a share of 8% to the total energy generation by 2012. As required by the national constitution, the Mexican energy sector is federally owned, providing a monopolist position of entire control to CFE, next to the regulatory energy agency CRE and SENER that defines energy policies. This policy results in certain limitations for private participation or foreign investment in the Mexican energy sector (EIA, 2010).

The national constitution also defines waste management as responsibility of each Mexican municipality. San Luis Potosí, a city of around 1 million inhabitants, generated 302.000 tons of waste in 2009 (INEGI, 2010). Since 2009, a private company, Red Ambiental, is managing the waste collection service. The local sanitary landfill Peñasco reported a delivery of approximately 929 tons of wastes per day in 2009. The disposal site operated since 1995 under unmanaged conditions and accumulated wastes that reached 22m height, until it was finally sanitised in 2009 (Red Ambiental, 2011).

Landfills are home to microbiological bacteria that degrade organic wastes in a process called anaerobic digestion where biogas is produced. Biogas generally consist of 50% CH_4 and 50% CO_2, both which are dangerous GHGs that contribute to climate change and cause problems for health and environment. Landfills are reported to have a share of 13% to global GHG emissions, as methane is even 21 times more harmful than CO_2 (IPCC, 2007).

Wastes are controlled by National Mexican Norms (NOM-083) but there is no integrated solid waste management or recycling system established and waste separation has become a profitable economic source for marginalised social groups called pepenadores, who depend on the garbage collection. A closure of the local landfill Peñasco in SLP would mean loss to 800 pepenadores´ livelihood and is one reason for the slow process of the planned biogas extraction in SLP. Social conflicts and laborious paperwork complicate these efforts.

In SLP recycling possibilities exist, but the few private initiatives are not perceived very well as it lacks a proper waste management system and mostly environmental education and awareness. The 3R principle is one of the possible strategies to make energetic use of wastes. There are several technologies to convert waste to energy, among them most commonly used is combustion at incineration plants, landfill gas capture and flaring, anaerobic digestion at biogas plants, pyrolisis, gasification, plasma arc gasification, blue tower technologies and organic rankine cycle facilities.

The produced energy can be used directly as biofuels, as heat or in CHP generation where the gas can be converted to be used as natural gas or electricity and be fed into the CFE grid. The benefit of avoided emissions and produced energy can furthermore be integrated to the international carbon trade market and create Certified Emission Reductions within the CDM network or NAMAs.

Financial concerns, governmental support, property rights, vision for the pepenadores etc. as well as site specific factors such as local climate, landfill design and operation, the amount and composition of the deposited wastes, influence the establishment of an exploitation of landfill gas and its potential production.

Applying the Mexican LFG Model 2.0, projections for 2014 estimate a maximum LFG generation of 2.633m^3 per hour for the landfill Peñasco, of which 1.290m^3 per hour were calculated to be recoverable, given a system collection efficiency of 49% and methane content of 50%. These data were calculated with an input of 302.000 tons of waste disposal in 2009 and an organic waste content of 74,2%. The results could mean a maximal power plant capacity of 2,1MW electricity and CERs of 4,047tCH_4 and 84,979tCO_2eq for 2014.

This study is, to the best of my knowledge, the first one of its kind in SLP and represents a second step in urban waste management analysis by the provision of a potentially obtainable biogas yield from urban wastes. This is supported by an incentive for decision makers to take advantage of the generated biogas on the landfills, whose exploitation can benefit health, environment and sustainable development in Mexico.

OUTLOOK

Energy and waste management are key building blocks of sustainable development. In all countries energy is the fundamental requirement for providing other basic life necessities such as food, water, shelter and clothing. Without energy, society is unable to maintain or improve living standards, meet the basic needs of citizens or maintain the socioeconomic infrastructure necessary for political and economic stability. Indeed, for the estimated 1.3 billion people who currently rely on traditional biomass for cooking and do not have access to electricity (IAEA, 2009), a lack of energy acts as barrier to industrialisation and escaping from the poverty trap.

Regardless, the total amount of wastes generated is expected to rise further in the future (EPA, 2009). Alarming is, that the society, generating mountains of trash, does not seem to realise that this reflects a rapid depletion of natural and energetic resources that are required to produce the goods and services they enjoy and that have been given to waste. During the last sixty years, the exploitation of resources for a dizzying production and excessive consumption of products and services has increased like never before, in order to adapt to a model of economic development, which paradoxically means a serious threat to human survival, when this trend will be followed (Cortinas de Nava, 2001).

Parallel to that, the disposition of these wastes is causing severe damage to the environment, occupying areas that could be used for more productive purposes and deteriorate air, water, soil and biota. It seems to be systematically forgotten that the planet is a closed ecosystem where everything left stays, or, according to the principles of energy and thermodynamics, material is neither created nor destroyed, only transformed. Taken into account the volume of organic wastes from households and other activities, a certain biomass potential can be suggested (INAFED, 2005; UNEP, 2009) that is in need to be taken advantage of.

Garbage is a serious topic. Its relation to health makes it crucial because it involves directly the citizen´s welfare. This issue is, perhaps along with the water topic, of highest social consideration and therefore well planned management is essential to ensure good governance of a community. Cities will keep growing and generating more waste. Landfills have become focus of public health and political and social conflicts, later due to the opacity in waste management and unilateral decisions from governmental authorities (EPA et al., 2011). It is therefore necessary to define and implement strategies that take into consideration the local needs. Here communication and information are the engines that raise awareness about the importance of these topics.

Mexico's current president Felipe Calderon´s financial reform attempts to implement sensible solutions for the country. Experts follow that the government is "not just failing to address costly energy inefficiencies, but making them worse by following ill-advised energy and economic policies" (Weintraub, 2008).
It remains to wait for the upcoming election on July 1st this year to see where Mexico´s policies and legislational regulations will head to and which future environmental and energy goals will be addressed.

REFERENCES

Acosta, J. L, 1986. El problema de la basura en la ciudad de México. In: Hacia una política ecológica: la ciudad de México, PSUM

Afgan N.H.et al., 1998. Gobaisi D.A.; Carvalho M.G.; Cumo M. Sustainable Energy Development. ElSevier

Aguilar-Virgen et al., 2011. Taboada-Gonzalez, P.A., Ojeda-Benítez, S.. Modelo mexicano para la estimación de generación de biogás. Article. Available at: http://www.revista.ingenieria.uady.mx/volumen15/modelo.pdf

Alternative Resources, Inc., 2008. Evaluating Conversion Technology for Municipal Solid Waste Management. In EESI, 2009.

AmeriCompass. 2007. Solid & Hazardous Waste. Available at: http://www.nrean.gc.ca/es/etb/crtc/cep/Mexico%20Municipal%20and%20Industrial%20Waste.pdf

Armijo de Vega Carolina, 2006. Waste Management in Mexico: key variables in play. The case of the Autonomous University of Baja California. Doctorthesis.

Armijo de Vega et al., 2003. Ojeda-Benítez S, Ramírez-Barreto E. Mexican educational institutions and waste management programmes: a University case study. Resources, Conservation and Recycling 2003; 39:283-96. In Maldonado, 2006. Available at: http://localeando.blogspot.de/2012/02/guia-para-el-aprovechamiento-o-quema.html

Aronica, S. et al, 2009. Bonanno, A., Piazza, V., Pignato, L., Trapani, S., Estimation of biogas produced by the landfill of Palermo, applying a Gaussian model., Waste Management, Vol. 29, No. 1, 2009, pp. 233-239. In Aguilar-Virgen et al., 2011.

Batool, S.A. and Chuadhry, M.N., 2008. The impact of municipal solid waste treatment methods on greenhouse gas emissions in Lahore, Pakistan., Waste Management, Vol. 29, No. 1, 2008, pp. 63-69. In Aguilar-Virgen et al., 2011.

BENLESA, 2010. En Cuidadanos en red. Available at: http://www.ciudadanosenred.com.mx/node/17408

Bernache Gerardo, 2003. The environmental impact of municipal waste management: the case of Guadalajara metro area. Centro de Investigaciones y Estudios Superiores de Antropologia Social, Guadalajara, Mexico. Resources, Conservation and Recycling 39 (2003) 223-237. ElSevier ScienceDirect. Available at: http://www.sciencedirect.com/science/article/pii/S0921344903000296

Bernache-Perez et al., 2001. Sánchez-Colón, Salvador; Garmendia, ana María; Dávila-Villareal, Arturo, Sánchez-Salazar María Elena. Solid waste characterisation study in the Guadalajara Metropolitan Zone, Mexico. Published by SAGE on behalf of ISWA. Waste Management & Research 2001: 19: 413-424. Available at: http://psp.sisa.my/elibrary/attachments/658_1-Guadalajaro.pdf

Bfai, 2007. Bundesagentur für Außenwirtschaft. Energiewirtschaft in Mexico 2007. Available at: www.lateinamerikaverein.de/files/.../4800_prom_e9xico_2c+bfai.pdf

Bhasin, K.C., 2009. Plasma Arc Gasification for Waste Management." Electronics For You Magazine. In EESI, 2009. Available at: http://www.electronicsforu.com/EFYLinux/efyhome/cover/February2009/Plasma-Arc-2.pdf, 2009.

BOKU, 2010. Organische Substanz in Abfällen.03 Chemie und Untersuchung von Abfällen. SS2010. Beurteilung der organischen Substanz in Abfällen. 2.2 Kohlenstoffbestimmung. Smidt. p.29. Available at: http://www.wau.boku.ac.at/fileadmin/_/H81/H813/IKS_Files/Lehre/813394/Folien/813_394_3_Chemie_und_Untersuchung_2010.pdf

Borzacconi et al., 1999. López Iván, Mallo Marisol, Martínez Javier. Potential Biogas Production from Sludges and MSW in Uruguay. Engineering School, Universidad de la República, CP 11300,J. Herrera y Reissig, 565, Montevideo, Uruguay. Available at: http://www.environmental-expert.com/articles/potential-biogas-production-from-sludges-and-msw-in-uruguay-32204/view-comments

Buenrostro and Bocco, 2003. Solid waste management in municipalities in Mexico: goals and perspectives. Morelia. Resources, Conservation and Recycling 39 (2003) 251-263. ElSevier Science Direct B.V. Available at: http://www.sciencedirect.com/science/article/pii/S0921344903000314

Buenrostro Delgado, O. et al., 2006. Ojeda-Benítez, Sara; Márquez-Benavides, Liliana. Comparative analysis of hazardous waste in two Mexican regions. Waste Management 27 (2007) 792-801. ScienceDirect. Available at: http://www.sciencedirect.com/science/article/pii/S0956053X0600136X

Buenrostro Otoniel et al., 2001a. Bocco G., Vence J. Forecasting the generation of urban solid waste in developing countries. A case study in Mexico. J Air Waste Management Association 2001c; 51(1): 86-93. In Maldonado, 2006.

Buenrostro Otoniel et al., 2001b. Bocco Gerardo, Bernache Gerardo. Urban solid waste generation and disposal in Mexico: a case study. Instituto de Investigaciones sobre Recursos Naturales, Universidad Michoacana de San Nicolás de Hidalgo, Morelia, Michoacan, Mexico. Waste Management & Research 2001: 19: 169-176. ISWA, 2001. ISSN 0734-242X Available at: http://wmr.sagepub.com/content/19/2/169.short

Buenrostro Otoniel et al., 2001c. Bocco, Gerardo; Cram, Silke. Classification of sources of municipal solid waste in developing countries. Resources, Conservation and Recycling 32 (2001) 29-41. ElSevier. Available at: http://www.sciencedirect.com/science/article/pii/S092134490000094X

Buenrostro Otoniel et al., 2008. Márquez-Benavides, Liliana, Pinette Gaona, Francelia. Consumption patterns and household hazardous waste generation in an urban settlement in México. Instituto de Investigaciones Agrícolas y Forestales, Universidad Michoacana de San Nicolás de Hidalgo, Morelia, Michoacan, Mexico. Waste Management 28 (2008) S2-S6. ElSevier Ltd.. Available at: http://www.sciencedirect.com/science/article/pii/S0956053X08001426

Burden Melissa, 2008. Flint Journal. Fueling Flint's future: Biogas may energize attitudes as well. The biogas process. Available at: http://www.mlive.com/flintjournal/business/index.ssf/2008/10/melissa_burden_the_flint.html

Busch G. et al., 2009. Großmann J., Sieber M., Burckhardt M. A New and Sound Technology for Biogas from Solid Waste and Biomass. Water Air Soil Pollut: Focus (2009) 9:89-97. Springer Science + Business Media B.V. 2008. Available at: http://rd.springer.com/article/10.1007/s11267-008-9195-5

Camexa, 2010. Deutsch-Mexikanische Industrie- und Handelskammer. Available at: http://mexiko.ahk.de

Carabias Julia & Herrera Ana, 1986. La cuidad y su ambiente. Cuadernos Políticos, numero 45.Mexico DF. Pp.56-60.

Casa Alemana, 2010. B2B Renewable Energies. Available at: http://www.renewablesb2b.com/ahk_mexico/es/portal

Castillo-Berthier H., 1983. The Garbage Society; Caciquism in Mexico City. Mexico: UNAM Institute for Social Research. In Maldondado, 2006.

Castillo-Berthier H., 2003. Garbage work and society. Resour Conserv Recycling 2003; 39:193-210. In Maldonado, 2006.

Ceeres, 2010. Potential Biogas Yields. Available at: http://ceeres.eu/en/industrial.html

Cervantes Suarez Jose Antonio, 2012 pers. com. Municipalidad de SLP. Departamento de Ecologia y Aseo Publico.

CFE, 2010. Comisión Federal de Electricidad. Available at:
http://app.cfe.gob.mx/Aplicaciones/QCFE/EstVtas/PorTarifa.aspx

Chavez Cesar Rafael, 2009. Challenges to Landfill Biogas Projects in Mexico. SEMARNAT. Monterrey, Mexico, 2009.

Chiemchaisri, C. and Visvanathan, C.,1995. Greenhouse gas emission potential of the municipal solid waste disposal sites in Thailand., Journal of the Air & Waste Management Association (1995), Vol. 58, No. 5, 2008, pp. 629-35. In Aguilar-Virgen et al., 2011. Available at:
http://www.scielo.org.co/scielo.php?script=sci_nlinks&ref=000082&pid=S0120-56092011000300007000007&lng=en

Chow Pineda Irene Gilma, 2010. Analysis of the Potential of Biomass Energy Generation in Santiago de Chile. Universidad Autonoma de San Luis Potosí and Cologne University of Applied Sciences. Masterthesis.

Christophersen, M. et al,. 2001. Kjeldsen, P., Holst, H., Chanton, J., Lateral gas transport in soil adjacent to an old landfill: factors governing emissions and methane oxidation., Waste Management Research, Vol. 19, No. 6, 2001, pp. 595-612. In Aguilar-Virgen et al, 2011.

CIA, 2010. The World Factbook. Mexico. Available at: https://www.cia.gov/library/publications/the-world-factbook/geos/mx.html

Ciencia @ sanluispotosi.mx, 2006. Energías Alternativas. UASLP, IPICYT, Colegio de SLP. Article. Available at: http://www.ipicyt.edu.mx/storage-sipicyt/difusion/gacetaabril06.pdf

CONAFOR, 2007. SEMARNAT. Programa Nacional de Dendroenergía Forestal 2007-2012. Coordinación General de Producción y Productividad. Gerencia de Desarrollo Forestal. Available at:
http://www.conafor.gob.mx/portal/index.php/acerca-de-conafor/programa-estrategico-forestal-2025

Corral V. et al., 1995. Bernache G, Encinas L and Garibaldi L. A Comparison of Two Measures of Reuse and Recycling Behaviour: Self-Report and Material Culture. Journal of Environmental Systems 23 (4), 313-327. In Bernache-Perez et al., 2001.

Corral Verdugo V., 2003. Situational and personal determinants of waste control practices in northern Mexico: a study of reuse and recycling behaviours. Resources, Conservation and Recycling 2003: 39:265-81. In Maldonado, 2006.

Cortinas de Nava, Christina, 2001. Hacia un Mexico sin Basura. Bases e implicaciones de las legislaciones sobre residuos. Grupo Parlamentario del PVEM, Cámera de Diputados, LVIII Legislatura. ISBN 970-92949-0-3. 1st edition

CRE, 2010. Comisión Reguladora de Energía. Available at: www.cre.gob.mx

cuentame. Map of SLP. Available at:
http://cuentame.inegi.org.mx/monografias/informacion/slp/default.aspx?tema=me&e=24

Declaye Sébastien, 2009. Design, optimization and modeling of an organic Rankine cycle for waste heat recovery. University of Liege. Thesis.

Dreger Iara, 2007. Biogasgewinnung aus Biomassen der Agrarwirtschaft als ökologisch-ökonomische Lösung für die Region des oberen Uruguayflusses in Sübrasilien. Fachhochschule Köln. ITT. Masterthesis.

Dutt G., 2010. Energy for Sustainable Development, ElSevier. Available at:
http://www.elsevier.com/wps/find/journaldescription.cws_home/717028/description#description

Eaton Alex, 2008. IRRI-México. Programa de biogas. Methane to Market. International Renewable Resources Institute. Mexico.

EESI, 2009. Municipal Solid Waste as a Renewable Energy Feedstock.Issue Brief. Environmental and

Energy Study Institute. Available at: http://www.eesi.org/72109_mswbrief

EIA, 2009. International Energy Outlook. DOE/EIA-0484(2009). Available at: www.eia.doe.gov/oiaf/ieo/index.html

EIA, 2010. Energy Information Administration. Country Analysis Briefs: Mexico. Available at: http://www.eia.doe.gov/emeu/cabs/Mexico/pdf.pdf

EIU, 2010. Economist Intelligence Unit, sponsored by Siemens. Latin American Green City Index, 2010. Assessing the environmental performance of Latin America's major cities. Available at: http://www.siemens.com/entry/cc/en/greencityindex.htm?stc=wwccc024394

EnBW,2012. Energie Baden-Württemberg AG. Bioerdgas. Vom Biogas zum Bioerdgas. Available at: http://www.enbw.com/content/de/impulse/energiezukunft/bioenergie/bioerdgas/index.jsp;jsessionid=7857554F8A2EA721BB1C51B27B39B2AB.nbw05

Encinas L. et al. 1996. Valenzuela B and Garibaldi L. El Impacto Ecológico de los Desechos Sólidos en el Mundo Actual. Revista Universidad de Sonora: 37-42. In Bernache-Perez et al., 2001.

Energypedia, 2012. Mexico Country Situation. Available at: https://energypedia.info/index.php/Mexico_Country_Situation

Engler et al., wd. Economics and Environmental Impact of Biogas Production as a Manure Management Strategy. Texas A&M University. Available at: http://files.harc.edu/sites/gulfcoastchp/publications/economicsimpactbiogasproduction.pdf

Environmental Technology Center, 2000. Incineration. Available at: http://www.etc.org/technologicalandenvironmentalissues/treatmenttechnologies/incineration and http://www.etc.org/advanced-technologies/high-temperature-incineration.aspx

EPA et al., 2011. US Environmental Protection Agency, Comisión de Cooperativa Ecológica Fronteriza México-USA (COCEF) and International City/Country Management Association (ICMA) Latinamerica. Guía para el aprovechamiento o quema del biogás en rellenos sanitarios.

EPA, 2002. US Environmental Protection Agency. 25 Years of RCRA: Building on Our Past to Protect Our Future. Available at: http://www.epa.gov/epawaste/inforesources/pubs/k02027.pdf

EPA, 2005 and 2011. US Environmental Protection Agency. Landfill Methane Outreach Program. Mexico Landfill Gas Model Version 2.0. Available at: http://www.epa.gov/lmop/international/tools.html#a04

EPA, 2006a. US Environmental Protection Agency. Combustion Emissions from Hazardous Waste Incinerators, Boilers and Industrial Furnaces and Municipal Solid Waste Incinerators – Results from Five Star Grants and Research Needs. Office of Research and Development

EPA, 2006b. US Environmental Protection Agency. Global Mitigation of Non-CO2 Greenhouse Gases. Office of Atmospheric Programs (6207J), Washington, DC 20460. EPA 430-R-06-005. Available at: http://www.epa.gov/climatechange/Downloads/EPAactivities/GM_Cover_TOC.pdf

EPA, 2007. Terminology Reference System. Available at: http://iaspub.epa.gov/trs/trs_proc_qry.navigate_term?p_term_cd=TERMDIS&p_ter

EPA, 2009. Environmental Protection Agency. Energy Projects and Candidate Landfills.EPA Landfill Methane Outreach Program. Available at: http://www.epa.gov/lmop/proj/index.htm

EPA, 2009. US Environmental Protection Agency. User´s Manual Mexico Landfill Gas Model Version 2.0. Available at: http://www.epa.gov/lmop/documents/pdfs/users_manual_mexico_lfg_model_v2_2009.pdf

EPA, 2012. US Environmental Protection Agency. International Waste Activities. Available at: http://www.epa.gov/waste/hazard/international/index.htm

Estrella Válenzuela Gabriel, 2008. A social and environmental overview of solid waste management in Mexico. Waste Management 28 (2008) S1. ElSevier.

European Biogas Association. Available at: http://www.european-biogas.eu/eba/index.phpT

Fachagentur Nachwachsende Rohstoffe, 2007. Biogas-eine Einführung. Brochure

Fachagentur Nachwachsende Rohstoffe, 2010. Biogas. Available at: www.nachwachsende-rohstoffe.de, http://www.fnr-server.de/cms35/index.php?id=399http://leoswoodshop.com/images/

Fachagentur Nachwachsende Rohstoffe, 2011. Biogás. Pflanzen, Rohstoffe, Produkte. Bruchure

Fachverband BIOGAS , wd. Biogas – die Energie aus der Natur. Available at: http://www.biogas.org/edcom/webfvb.nsf/id

Fernandez Bremauntz Adrian, 2010. Progress of the State Programs of Action to Climate Change. SEMARNAT. National Institut of Ecology.

Figurereoa, 2009. Green Monumentum. Plantas de biogás en las grandes ciudades de México . Available at: http://www.greenmomentum.com/wb3/wb/gm/gm_content?id_content=2821

Flores R. et al, 2008. R. Munoz Ledo, B. B. Flores, K. I. Cano. Estimacion de la Generacion de Energia a partir de Biomasa para Proyectos del Programa de Mecanismo de Desarrollo Limpio. Revista Mexicana de Ingenieria Quimia, abril, ano/vol. 7, numero 001. Universidad Autonoma Metropolitiana –Iztapalapa, Mexico DF. Pp.35-39.

Garg A., Achari G., Joshi R.C., 2006. A model to estimate the methane generation rate constant in sanitary landfills using fuzzy synthetic evaluation. Waste Management Research, ISWA, 24(4), 363-375. In Aguilar-Virgen et al. 2011.

Garrison, 2010. USAID. Clean Energy & Climate Change Opportunities Assessment for USAID/Mexico. Final. Available at: http://pdf.usaid.gov/pdf_docs/PNADS950.pdf

Gaxiola E., 1995. Estudio de Residuos Domésticos en la Cuidad de Mexicali. M.Sc. Thesis, Universidad Autónoma de Baja California, Manuscript. In Bernache-Perez et al., 2001.

Germany Trade and Invest, 2010a. Mexikanischer Energiesektor benötigt bis 2024 Investitionen von über 100 Mrd. US$. Brochure

Germany Trade and Invest, 2010b. Mexiko wendet sich Erneuerbaren Energien zu. Brochure.

GIZ, 2010. Programa Gestion Ambiental Urbana e Industrial en Mexico (2010-2013). Macht Axel. Mexico

GMI, 2011. Municipal Solid Waste Technical Proceedings from Global Methane Initiative Events. Landfill experiences Mexico. Available at: http://www.globalmethane.org/tools-resources/landfill_techproceeds.aspx

GMI, 2012. Global Methane Initiative. Mexico. Landfill sites registered in Mexico. Available at: http://globalmethane.org/partners/mexico.aspx

Gobierno de Mexico, 2007. Programa Sectorial de Energía 2007-2012. Secretaria de Energía.

Gobierno del Estado de Mexico, 2002a. Secretaria de Ecología. Manual para la Supervision y Control de Rellenos Sanitarios. Mexico DF.

Gobierno del Estado de Mexico, 2002b. Secretaria de Ecología. Manual para la Rehabilitacion, Clausura y Saneamiento de Tiraderos a Cielo Abierto en el Estado de Mexico. Mexico, DF.

Gobierno del Estado de Mexico, 2003. Secretaria de Ecología. Guia para el Desarrollo, Presentación y Evaluación de Proyectos Ejecutivos para Rellenos Sanitarios. Mexico DF.

Gobierno del Estado de San Luis Potosí. Enciclopedia de los Municipios de México. ESTADO DE SAN LUIS POTOSÍ. SLP. Available at: http://www.inafed.gob.mx/work/templates/enciclo/sanluispotosi/municipios/24028a.htm

Godoy Avendano Emma Valentina, 2010. Landfill Gas Generation and Use Alternatives as well as Financing Possibilites Through the Clean Development Mechanism. Universidad Autonoma de San Luis Potosí and Cologne University of Applied Sciences. Masterthesis

Goldemberg José et al., 2009. Thomas B. Johansson, Amulya K.N. Reddy, Robert H. Williams. Energy efficiency from the perspective of developing countries. Energy for Sustainable Development, Volume 1, Issue 2, July 1994, Pages 28-34. Published by Elsevier Inc.. Available at: http://www.sciencedirect.com/science/article/pii/S0973082608600290

Gomez, Guadalupe et al., 2008. Meneses Montserrat, Ballinas Lourdes, Castells Francesc. Characterization of urban solid waste in Chihuahua, Mexico. Department dÉnginyeria Química, Universidad Rovira i Virgili, Tarragona, Spain. Facultad de Ciencias Químicas, Universidad Autónoma de Chihuahua, Mexico. Waste Management 28 (2008) 2465-2471. ElSevier ScienceDirect. Available at: http://www.sciencedirect.com/science/article/pii/S0956053X07004126

Gonzalez Mariana, 2011. World Resources Institute. Environmental Entrepreneurs: Mexico's YoReciclo Recycles for a Profit. Available at: http://www.wri.org/stories/2011/05/environmental-entrepreneurs-mexicos-yoreciclo-recycles-profit

Govea Tello Mayra Denise, 2012 pers. com. Municipalidad de SLP. Directora General del Departamento de Ecología y Aseo Publico.

GTZ, 2005. Urban Soild Waste Management in Mexico. Environment and Infrastructure Division. Factsheet. Available at: http://www2.gtz.de/dokumente/bib/05-0756b.pdf

Guerrero Cordero, Guillermo, 2012 pers.com. Engineer at ENERGREEN

Guzzone and Schlagenhauf, 2007. Garbage in, energy out – landfill gas opportunities for CHP projects. Cogeneration and On-Site Power Production Available at: http://www.cospp.com/articles/print/volume-8/issue-5/features/garbage-in-energy-out-landfill-gas-opportunities-for-chp-projects.html

Hernández, 2009. In Milenio. Planta de biogas en Bordo Poniente. Available at: http://www.milenio.com/node/309520

Herrera Flores Sandra D., 2007. SEMARNAT. Under Secretary of Environmental Regulation and Protection. Bonn, Germany.
http://siteresources.worldbank.org/INTLACREGTOPURBDEV/Resources/840343-1178120035287/ModelMonterrey.pdf
http://www.biomassmagazine.com/article.jsp?article_id=2144&q=&page=1
http://www.electronicsforu.com/EFYLinux/efyhome/cover/February2009/Plasma-Arc-2.pdf

Hult M.& Lennung S., 1980. Towards a Definition of Action Research: A Note and Bibliography. Participatory Action Research (PAR). Journal of Management Studies (17:2), 1pp. 242–250.

IAEA, 2005. International Atomic Energy Agency. Energy Indicators for Sustainable Development: Guidelines and Methodologies, Vienna. Available at: http://www.nea.is/media/orkustefnunefnd/energy+indicators+for+SD.pdf

IAEA, 2009. Nuclear Technology for Sustainable Future. Energy Poverty. Available at: http://www.iaea.org/Publications/Booklets/NuclearTechnology/rio0612.pdf

IEA Bioenergy, 2010. Braun et al. Biogas from Energy Crop Digestion. Available at: http://biogasmax.co.uk/media/iea_1_biogas_energy_crop__007962900_1434_30032010.pdf

IEA Bioenergy, 2010. Lukehurst et. al. Utilisation of digestate from biogas plants as biofertiliser. Available at: http://www.iea-biogas.net/_download/publi-task37/Task37_Digestate_brochure9-2010.pdf

IEA, 2010. International Energy Agency. Country Information: Mexico. Energy Policies and Measures Database. Available at: http://www.iea.org/country/m_country.asp?COUNTRY_CODE=MX&Submit=Submit

IEA, 2012. International Energy Agency. World Energy Outlook. Energy and Development. Access to Electricity. Available at: http://www.iea.org/weo/electricity.asp

IISD, 2010. International Institute for Sustainable Development Energy-promoting sustainable development through secure, clean energy. Available at: http://www.iisd.org/energy/

INAFED, 2005. Instituto Nacional para el Federalismo y el Desarrollo Municipal. Available at: http://www.inafed.gob.mx/

INE, 2007. Instituto Nacional de Ecología. Estimación de los factores de emisión.

INEGI, 2010. Mexico en cifras. San Luis Potosí, SLP. Available at: http://www.inegi.org.mx/sistemas/mexicocifras/default.aspx?ent=24

INEGI, 2010. Anuario estadístico de San Luis Potosí. Available at: http://www.inegi.org.mx/prod_serv/contenidos/espanol/biblioteca/default.asp?accion=2&upc=702825201449&seccionB=bd

INEGI, 2010. El sector energético en Mexico. Available at: http://www.inegi.org.mx/prod_serv/contenidos/espanol/biblioteca/default.asp?accion=2&upc=702825002023&seccionB=bd

IPCC, 2006. Waste. IPCC Guidelines for National Greenhouse Gas Inventories. Institute for Global Environmental Strategies (IGES), Japan. http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol5.html

IPCC, 2007. Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Core Writing Team, Pachauri, R.K. and Reisinger, A. (Eds.) IPCC, Geneva, Switzerland. pp 104. Available at: http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

Jimenez Rodolfo Díaz et al., 2003. Claudio Alatorre Frenk, Omar Masera. El Uso de Bioenergía en los Hogares: Impactos Ambientales y en la Salud. Grupo Interdisciplinario de Tecnologia Rural Apropriada

Juarez Perez Jesus, 2012 pers.com. Engineer at the Municipalidad de SLP.

Karakosta et al., 2010. Charikleia Karakosta and Dimitris Askounis, Developing countries' energy needs and priorities under a sustainable development perspective: A linguistic decision support approach. National Technical University of Athens, School of Electrical and Computer Engineering, Management & Decision Support Systems Lab (EPU-NTUA), 9, Iroon Polytechniou str., 15780, Athens, Greece. Energy for Sustainable Development, Volume 14, Issue 4, December 2010, Pages 330-338. Available at: http://www.sciencedirect.com/science/article/pii/S0973082610000396

Kong I.C., 2008. Microbial characteristics associated with six different organic wastes undergoing anaerobic decomposition in batch vial conditions. Waste Management Research, ISWA, 26(3), 261-266. In Aguilar-Virgen et al., 2011.

Kothari Richa et al., 2010. V V Tyagi, Ashish Pathak. Waste-to-energy: A way from renewable energy sources to sustainable development. Renewable and Sustainable Energy Reviews (2010) Volume: 14, Issue: 9, Publisher: Elsevier Ltd, Pages: 3164-3170. Available at: http://www.mendeley.com/research/wastetoenergy-way-renewable-energy-sources-sustainable-development-9/

Kumar S. et al, 2004b. Mondal A., Gaikwad S., Devotta S., Singh R. Qualitative assessment of methane emission inventory from municipal solid waste disposal sites: a case study. Atmospheric Environment, 38(29), 4921-4929. In Aguilar-Virgen et al., 2011.

Kumar S. et al., 2004a. Gaikwad S.A., Shekdar A.V., Kshirsagar P.S., Singh R.N. Estimation method for national methane emission from solid waste landfills. Atmospheric Environment, 38(21), 3481-3487. In Aguilar-Virgen et al., 2011.

LAERFTE, 2012. Ley Para el Approvechamiento de Energias Renovables y el Financiamiento de la Transicion Energetica. Camera de Diputados del H. Congreso de la Unión. Secretaria General. Ultima Reforma DOF 12-01-2012.

Lee et al., 2007. J. Bogner, A. Toefy. Landfill Gas CDM Projects: Current Trends and Future Opportunities for Developing Countries.

LFG Consult, 2007. Case studies of CDM - Landfill Gas Projects Monterrey, Mexico (Benlesa).

LGEEPA, 2012. Ley General para el Equilibrio Ecológico y la Protección al Ambiente. Camera de Diputados del H. Congreso de la Unión. Secretaria General. Ultima Reforma DOF 04-06-2012.

LGPGIR, 2012. Ley General para la Prevencion y Gestion Integral de los Residuos. Camera de Diputados del H. Congreso de la Unión. Secretaria General. Ultima Reforma DOF 30-06-2012.

LMOP, 2008. Landfill Methane Outreach Program. Landfill Gas Energy: Fueling the Economy and a Sustainable Energy Future While Improving the Environment. US Environmental Protection Agency. EPA. Available at: http://www.epa.gov/lmop/docs/LMOPGeneral.pdf

Lynch Richard, 2002. An Energy Overview of Mexico. U.S. Department of Energy. Office of Fossil Energy, 1000 Independence Avenue, Washington, D.C. 20585 USA. Available at: http://www.geni.org/globalenergy/library/national_energy_grid/mexico/LatinAmericanPowerGuide.shtml

M2M, 2011. Methane to Markets. Landfills. Factsheet. Available at: http://www.globalmethane.org/tools-resources/factsheets.aspx#m2mlandfs

Machado S.L. et al., 2009. Carvalho M.F., Gourc J., Vilar O.M., Nascimento J.C.D. Methane generation in tropical landfills: Simplified methods and field results. Waste Management, 29(1), 153-161. In Aguilar-Virgen et al., 2011.

Macias-Corral Maritza et al., 2008. Zohrab Smani, Adrian Hanson, Geoffrey Smith, Paul Funk, Hui Yu, John Longworth. Anaerobic digestión of municipal solid waste and agricultural waste and the effect of co-digestion with dairy cow manure. Bioresource Technology 99 (2008) 8288-8293. ElSevier.

Maldonado, L., 2005. The economics of urban solid waste reduction in educational institutions in Mexico: A 3-year experience. Centro de Investigación y de Estudios Avanzados, Department of Applied Physics, Unidad Merida, Yucatan, Mexico. Resources, Conservation and Recycling 48 (2006) 41-55. El Sevier ScienceDirect. Available at: http://biblioteca.cinvestav.mx/indicadores/texto_completo/cinvestav/2006/126673_1.pdf

Manzanarez, 2009. Una mirada al tiradero municipal de Peñasco, SLP. La Jornada Ecológica. Available at: http://www.jornada.unam.mx/2009/06/01/eco-i.html

Marchaim, 1992. Food and Agriculture Organisation FAO. Biogas processes for sustainable development. Available at: http://www.fao.org/docrep/t0541e/t0541e00.HTM, http://www.fao.org/docrep/t0541e/T0541E03.htm#Chapter%20two:%20Introduction%20and%20overview

Meraz, L. et al, 2008. Aranda, C., Domínguez, A., Producción de metano en relleno sanitario: Un Modelo Cinético Fractal., Memorias del XVI Congreso Nacional de Ingeniería Sanitaria y Ciencias Ambientales: La sustentabilidad en las grandes ciudades, AIDIS-FEMISCA, México, 2008, pp. 1-7. In Aguilar-Virgen et al, 2011.

Minnesota Resource Recovery Association, 2011. Waste to Energy. Mechanical separation. Available at: http://www.mnresourcerecovery.com/index.php/faqs/

Moser and McIllwaine, 2001. Implementing Urban Participatory Climate Change Adaptation Appraisals: A Methodological Guideline. Working Paper No. 5, May 2010. The Global Urban Research Centre (GURC), The University of Manchester, M13, 9PL UK

NAMA Database, 2011. Latin America Projects. Mexico. Available at: http://namadatabase.org/index.php/Category:Latin_America

National Center for Environmental Research,wd. Washington, DC. Available at: http://epa.gov/ncer/publications/research_results_needs/combustionEmmissionsReport.pdf

Natural Resources Canada, 2010. Energy Resources. Available at: http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/eng/bioenergy/biomass_resources.html

NEA, 2002. National Environment Agency. Waste Management backup. Solid Waste Management Infrastructure. Waste to Energy Plants. Available at: http://app2.nea.gov.sg/wastemanagementinfrastructure.aspx

NMX-AA-015-1985. Norma Oficial Mexicana. Dirección General de Normas. Secretaria de Comercio y Fomento Industrial. Protección al Ambiente- Contaminación del Suelo- Residuos Sólidos Municipales-Muestreo-Método de Cuarteo. México

NMX-AA-019-1985. Norma Oficial Mexicana. Dirección General de Normas. Secretaria de Comercio y Fomento Industrial. Protección al Ambiente- Contaminación del Suelo- Residuos Sólidos Municipales-Peso Volumétrico "in situ". México

NMX-AA-022-1985. Norma Oficial Mexicana. Dirección General de Normas. Secretaria de Comercio y Fomento Industrial. Protección al Ambiente- Contaminación del Suelo- Residuos Sólidos Municipales-Selección y Cuantificación de Subproductos. México.

NMX-AA-061-1986. Norma Oficial Mexicana. Dirección General de Normas. Secretaria de Comercio y Fomento Industrial. Protección al Ambiente- Contaminación del Suelo- Residuos Sólidos Municipales-Determinación de la Generación. México.

NMX-AA-091-1987. Norma Oficial Mexicana. S Dirección General de Normas. Secretaria de Comercio y Fomento Industrial. Calidad del suelo – Terminología. México.

Ojeda-Benítez et al., 2003. Armijo de Vega C., Ramírez-Barreto M.E. Characterization and quantification of household solid wastes in a Mexican city. Resources, Conservation and Recycling 39, 211-222. In Gomez et al, 2008.

Orozco, 1990. El caso de los Desechos Sólidos Municipales. SEDUE. Instituto Nacional de Ecología. Taller de Educación Ambiental no Formal.

Pbs, 2012. FRONTLINE. Sources of Worlds CO2 Emissions. Available at: http://www.pbs.org/wgbh/pages/frontline/heat/etc/worldco2.html

Pemex, 2008. Available at: http://www.pemex.com/index.cfm?action=content&sectionID=4&catID=10015

Phillips PS. et al., 1999. Read AD, Bates MP. UK Waste minimization clubs: a contribution to sustainable waste management. Resour Conserv Recycling 1999;27:217-47. In Maldonado, 2006.

Phillips, D. et al., 1984. Restrepo, I. & Rathje, W.L.. El Proyecto Basura. American Behavioral Scientist 2 8 (1):139-153. In Bernache-Perez et al., 2001

Plastic Omnium, 2011. Available at: http://www.plasticomnium.com/en/inside-pastic-omnium.html

Potogas, 2011. Available at: http://www.potogas.com/gm_gas.html

Rathje, W. & McCarthy, M., 1977. Regularity and Variability in Contemporary Garbage. In Bernache-Perez et al., 2001

Rathje, W., Reilly, M. & Hughes, W., 1985. Household Garbage and the Role of Packaging. Report to the Solid Waste Council, American Paper Institute. The Garbage Project, University of Arizona, Tucson.

Recikla, 2012. Available at: https://www.facebook.com/reciklasanluis

Red Ambiental, 2011. Available at: http://www.redambiental.com/

REN 21, 2008. Renewables 2007. Global Status ReportRenewable Energy and Sustainable Development. Available at: http://isi.kfupm.edu.sa/summary.aspx?sid=4451

Restrepo Cadavid Paula, 2010. WEC Energy for Megacities Study. Mexico City Case Study

Restrepo I., Bernache G. & Rathje W., 1991. Los Demonios del Consumo: Basura y Contaminación. Centro de Ecodesarrollo, Mexico. In Bernache-Perez et al., 1999.

Restrepo, I. & Phillips, D., 1982. La basura: Consumo y Desperdicio en el Distrito Federal, Instituto Nacional del Consumidor, Mexico D.F.; Centro de Ecodesarrollo (CECODES), México (1985) 2d. edition. Available at: http://www.iberlibro.com/basura-Consumo-desperdicio-Distrito-Federal-Restrepo/894716296/bd

Rodriguez Olalde Moises, 2012 pers.com. Head of the pepenadores at Penasco in SLP.

Roth Joshua G. et al., 2002. SCS Engineers. LFG-to-Energy Development in Mexico. Francisco Grajales Gravioto. The World Bank.

Rüd Sören, 2011. Programm Städtisch-Industrielles Umweltmanagement (SIU) in Mexiko (2010-2013). GIZ. Mexico DF

Rüd Sören, wd. Achieving sustainable wastewater and organic solid waste management taking advantage of the Clean Development Mechanism. GIZ. Mexico DF.

Schilli, Joseph W., 2004. Using Gasification to Process Municipal Solid Waste. HDR Innovations. In EESI, 2009. Available at: http://www.hdrinc.com/Assets/documents/Publications/InnovationsPFS/Winter2004/UsingGasificationtoProcessMSW.pdf.

Schübeler P., 1997. Reports and reviews. Waste Manage Res 1997a; 15:437-48. In Maldonado, 2006.

Schübeler P. et al., 1996. Wehle K, Christensen J. Conceptual Framework for Municipal Solid Waste Management in Low-Income Countries, Environmental and Natural Resources Group and Urban Development Programme, UWDP, New York, USA, 1996. In Maldonado, 2006.

Schübeler P. et al., 1997. A conceptual framework for municipal solid waste in developing countries. Waste Manage Res 1997b; 15:437-48. In Maldonado, 2006

SCS Engineers, 2005a. Pre-Feasibility Study for Landfill Gas Recovery and Energy Production at the Queretaro Landfill. Queretaro, Mexico.

SCS Engineers, 2005b. Pre-Feasibility Study for Landfill Gas Recovery and Energy Production at the Landfill in Chihuahua, Mexico.

SEDESOL, 1999. Waste Generation in Mexico. In Cortinas de Nava, 2001.

SEDUE, 1998. Waste Generation in Mexico. In Cortinas de Nava, 2001.

SEISA, 2007. Available at:
http://www.seisa.com.mx/index.php?option=com_content&task=view&id=54&Itemid=65&elprim=63

SEMARNAT and GTZ, 2004. Guía de Cumplimiento de la NOM-083-SEMARNAT-2003. Mexico DF

SEMARNAT and GTZ, 2005. Guía para la Realización de Planes de Regularización Conforme a la NOM-083-SEMARNAT-2003. Mexico DF

SEMARNAT, 2004. Norma Oficial Mexicana 083. Especificaciones de protección ambiental para la selección del sitio, diseño, construcción, operación, monitoreo, clausura y obras complemantarias de un sitio de disposición final de residuos urbanos y de manejo especial.

SEMARNAT, 2007. Lic Felipe Calderón Hinojosa, Ing. Juan Elvira Quesada, Ing. Sandra Denisse Herrera Flores, Lic. Mauricio Limón Aguirre. Política y Estrategias para la Prevención y Gestion Integral de los Residuos en Mexico.

SEMARNAT, 2009. Conjunto de Indicadores Clave 2009. Sistema Nacional de Indicadores Ambientales. Mexico DF

SENER and GTZ, 2006. Renewable Energies for Sustainable Development in Mexico. Available at: http://www.gtz.de/en/praxis/12538.htm

SENER, 2008. Energy Statistics. Available at:
http://www.sener.gob.mx/res/Acerca_de/DirectivaDeterminacionPreciosMaximos.pdf

SENER, 2009. Prospectiva del Sector Electrico 2009-2024.

SENER, 2010a. Secretaria de Energía. Cuarto informe de energía. Available at:
http://www.energia.gob.mx/webSener/portal/electricidad_2.htm and
http://www.energia.gob.mx/portal/Default.aspx?id=1601

SENER, 2010b . Balance Nacional de Energía 2010. Available at:
http://www.energia.gob.mx/portal/publicaciones.html

SENER, 2011. Estrategia nacional para la transicion energetica y el aprovechamiento sustentable de la energía.

SENER, 2012. Estrategia Nacional de Energía 2012 – 2026. Available at:
http://www.sener.gob.mx/res/PE_y_DT/pub/2012/ENE_2012_2026.pdf

SIE-BNE, 2010. Primary Energy Consumption by Source. In Energypedia, 2012.

Silberberg Martin, 2004. Hydrocarbon. Chemistry: The Molecular Nature of Matter and Change. New York: McGraw-Hill Companies, 2004.

Sims, Bryan, 2008. Proving Out Plasma Gasification.Biomass Magazine. In EESI, 2009.

Sipilä Kai, 2002. Municipal and Commercial Solid Waste for Pyrolysis (Oils) and Gasification Markets. VTT Processes. In EESI, 2009. Available at: http://www.pyne.co.uk/docs/488.pdf

SLP Expres, 2011. Comenzaría este ano extracción de biogás en Santa Rita. Journal. Available at:
http://www.sanluis.gob.mx/homepage/noticia.php?id=3661

Solar Millenium AG, 2012. Blue Tower Technology. Available at:
http://www.solarmillennium.de/english/archives/technology/innovation/blue-tower/index.html

Spillmann, wd. Abfall und Deponiewirtschaft. Universität Rostock. Fachbereich Landeskultur und Umweltschutz. Institut für Landschaftsbau und Abfallwirtschaft.

Stadtwerke Karlsruhe, 2010. Schema einer Deponiegasanlage. Available at: http://www.stadtwerke-karlsruhe.de/swka-de/inhalte/service/interaktiv/bilder_und_grafiken.php#deponie
Swedish Biogas International, 2010. US Department of Energy. About Biogas. Biogas Plant. Available at: http://www.swedishbiogas.com/us/about-biogas

Texas Comptroller of Public Accounts, 2008. The Energy Report 2008: Chapter 18 Municipal Solid Waste Combustion. In EESI, 2009.

Trejo-Vázquez and Cespedes-Soto,1989. The recycling from municipal solid wastes in Mexico. J. Resources Management Technology 1989;17:15-7 in Maldonado, 2006.

UN, 2010. United Nations. Millennium Development Goals. Available at: http://www.un.org/millenniumgoals/

UNDP, 2010. United Nations Development Programme. Available at: http://www.undp.org/energy

UNEP, 2007. Solid Waste Management Sourcebook: Regional Overviews and Information Sources, Latin America and the Caribean. Available at: http://www.unep.or.jp/ietc/ESTdir/Pub/MSW/RO/latin_a/topic_a_asp

UNEP, 2009. United Nations Environment Programme. Converting Waste Agricultural Biomass into a Resource, Compendium of Technologies United Nations Environmental Programme, Division of Technology, Industry and Economics, International Environmental Technology Centre Oska/Shiga, Japan, page 4-6

UNFCCC, 2004. Clean Development Mechanism Project Design Document Form (CDM-PDD). Version 02.

UNFCCC, 2007. CDM Project Activities. Available at: http://cdm.unfccc.int/Projects/index.html.

UNFCCC, 2010. Methodological tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site. Version 05.1.0. CDM. EB 61 Report. Annex 10.

UNFCCC, 2011. Methodological tool "Emissions from solid waste disposal sites". Version 06.0.1. EB 66 Report Annex 46.

UNFCCC, 2012. Project 0153 : AWMS Methane Recovery Project MX05-S-11, Baja California, México. Available at: http://cdm.unfccc.int/Projects/DB/TUEV-SUED1133542985.51/view

University of Adelaide. Basic Biogas. Available at: http://www.adelaide.edu.au/biogas/basic/

Unmann, 2009. CDM Markt kompakt, Mexiko. Germany Trade and Invest. DEG Bankengruppe.

Vandevivere P.et al., wd. L De Baere and W. Verstraete. Types of anaerobic digesters for solid wastes.

Walter, G.R.,2003. Fatal flaws in measuring landfill gas generation rates by empirical well testing., Journal of the Air & Waste Management Association (1995), Vol. 53, No. 4, 2003, pp. 461-468. In Aguilar-Virgen et al., 2011. Available at: http://www.scielo.org.co/scielo.php?script=sci_nlinks&ref=000105&pid=S0120-56092011000300007000030&lng=en

WCEC, 1997. World Commission on Environment and Development. Our Common Future, Oxford, UK: Oxford University Press. In IAEA, 2005

Weintraub, 2007. Center for Strategic and International Studies (CSIS). Washington D.C. The Energy Situation in the Western Hemisphere. Available at: http://csis.org/files/media/csis/pubs/sw_faee_072007.pdf

Weintraub, 2008. The Energy Situation in the Western Hemisphere. in World Politic Review (WPR). Available at: http://www.worldpoliticsreview.com/trend-lines/915/the-energy-situation-in-the-western-hemisphere

Westinghouse Plasma Corporation, 2007. What is Plasma & Gasification? Westinghouse Plasma Corporation. In EESI, 2009. Available at: http://www.westinghouse-plasma.com/technology_solutions/what_is_plasma_gasification.php.

Williams Jeremy, 2008. LFG to Fuel. SLG. Southern Legislative Conference.

World Bank, 2003. ESMAP/DIDA: Energía del biogas de rellenos Sanitarios para la Región LAC Buenas Prácticas, Difusión y Programa Futuro. Available at: http://worldbank.org

World Bank, 2004. Handbook for the Preparation of Landfill Gas to Energy Projects in Latin America and the Caribbean. Available at: http://www.bancomundial.org.ar/lfg/gas_access_008.htm

World Bank, 2004. Report Reforming Infrastructure. Privatization, Regulation and Competition. Policy Reseach Report.

World Energy Council, 2011. Energy Profile Mexico. The Structure of Mexicos Energy Sector. Available at: http://www.wecmex.org.mx/perfil.html

World Resources Institute, 2010. In Gonzalez, 2011. www.ine.gob.mx/publicaciones/libros/457/estimacion3.pdf

Zafar, Salman, 2009. Gasification of Municipal Solid Waste." Earthtoys Magazine. In EESI, 2009. Available at: http://www.earthtoys.com/emagazine.php?issue_number=09.06.01&article=zafar

Zeit Online, 2010. Mexiko. Zuhause auf der größten Müllkippe Lateinamerikas. Available at: http://www.zeit.de/gesellschaft/zeitgeschehen/2010-11/ueberleben-muellkippe-mexiko

Zhang, H. et al., 2008. He, P., Shao, L., Methane emissions from MSW landfill with sandy soil covers under leachate recirculation and subsurface irrigation., Atmospheric Environment, Vol. 42, No. 22, 2008, pp. 5579-5588. In Aguilar-Virgen et al., 2011. Available at: http://www.scielo.org.co/scielo.php?script=sci_nlinks&ref=000107&pid=S0120-56092011000300007000032&lng=en

The interviewed experts appear in the references as personal comment.

ANNEX

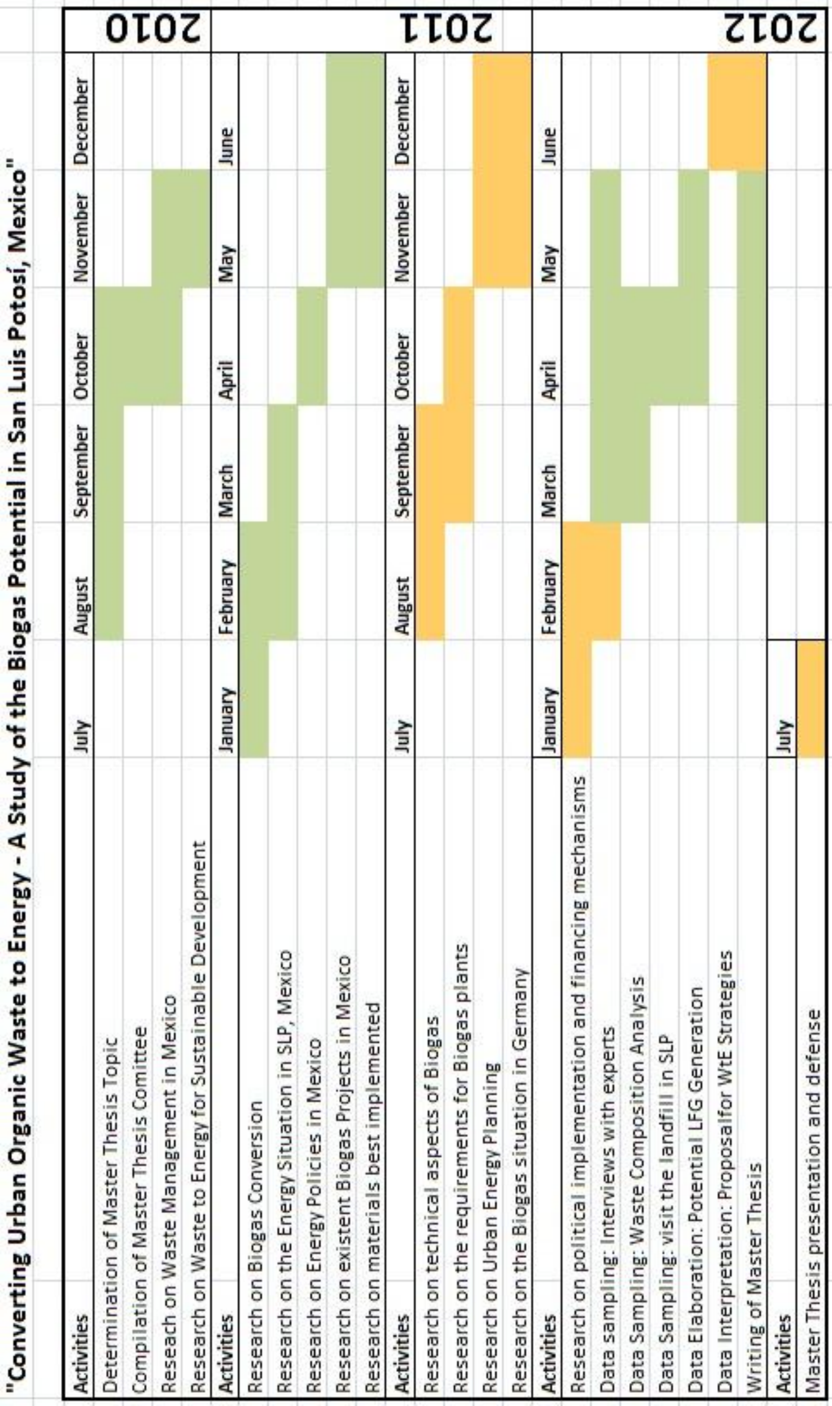

Figure 29: Chronogram of Activities where green marks the time in SLP and yellow the time in Cologne