Analysis of Different Municipal Solid Waste Management Systems in Santiago de Chile

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Abstract

Megacities are characterized by a rapid population growth, concentrating considerable quantities of people; they absorb an immense amount of resources and generate vast quantities of solid waste, thus impacting the environment and its use as a sink. Adequate management of municipal solid waste is critical to the health of urban residents, and to the protection of the environment, therefore to the sustainability of cities.

It is well known, that a rising standard of living increases the waste generation rate. The Metropolitan Region of Santiago (MRS) has experienced a large growth in population in recent years and a rise in the standard of living. As a consequence, the flow of municipal solid waste has increased from 1.8 million tons in 1995 to 3.0 million tons in 2007.

The municipal solid waste management (MSW) system in the MRS has been evaluated under sustainability aspects. The role of the informal waste sector in the MSW management system of the city has been identified. Possible scenarios of waste management have been developed and also evaluated under sustainability aspects.

Data about the current situation of MSW management in Santiago de Chile were collected during field research, interviews with stakeholders, field visits and by a systematic evaluation of already existing documentary literature. The Integrative Sustainability Concept of the Helmholtz Association provided a conceptual framework for the study.

To assess the current waste management situation in the MRS, the most relevant sustainability indicators were identified, their current values were determined and their target values were selected. The MSW flux (indicator 1) increased from 0.8 to 1.2 kg/(person·day) between 1995 and 2007. This value compares with that of countries with an even larger gross domestic product. MSW management in the region is based on final disposal at sanitary landfills, however, the solid waste collected does not undergo any previous biological or thermal treatment to reduce its organic carbon content (indicator 2), therefore, the current value for this indicator is cero. The biogenic fraction of the solid waste deposited in landfills decomposes in anaerobic conditions, generating greenhouse gas emissions (indicator 3), whose value in the MRS is 143 kg $CO_{2\text{-eq}}$/(person·year). The recycling rate in the MRS is roughly 14% (indicator 4), and there is no energy recovery from waste. The publicly organized collection and separation of recyclable materials is not carried out on a large scale. In contrast, the informal sector plays a significant role in the collection and separation of recyclable materials. The informal primary collectors earn in average 76% of an individual household income (indicator 5). Finally, as an economic parameter, the share of gross domestic product spent on MSW management (indicator 6) was chosen, the value for this indicator is currently 0.22% (US$17/(person·year)).

A comparison between current and target values showed that the largest sustainability deficits are in the current amount of MSW deposited at sanitary landfills without any pre-treatment, and the emission values of greenhouse gases associated with waste treatment and final disposal.

To find out if and how the informal waste sector contributes to sustainability, experiences of organization of informal primary collectors in Latin America were analyzed systematically. The key factors and key stakeholders, which have an influence on their working conditions, were identified. The identified key factors include, among others, the existence of a legal framework for the informal waste sector; the existence of alliances with production companies guaranteeing a reliable industrial market for secondary raw materials and expansion of activities beyond collection of recyclables, towards further processing and upgrading to add more economic value to materials collected. Key stakeholders included people from the public and the private sector, from the civil society and from NGOs.

Three explorative scenarios were developed for the year 2030: Business as Usual (BAU), Collective Responsibility (CR), and Market Individualism (MI). Waste generation, waste composition and different practices of waste collection, recovery and treatment were taken into account for the scenarios formulation.

The BAU scenario incorporated separate collection of biowaste, recyclable materials with some participation of organized primary collectors and an expansion of drop-off systems. The mechanical sorting of mixed waste to recover materials for recycling was introduced. The utilization of landfill gas as an energy source is promoted in this scenario and the production of biogas in anaerobic digestion plants was implemented.

The CR scenario incorporated extended separate collection of biowaste, a large commitment to work together with the primary waste collectors and an expansion of drop-off systems. The mechanical and mechanical biological treatment of mixed waste was introduced to recover materials for recycling and to produce alternative combustibles, to be used in cement kilns. The utilization of landfill gas as an energy source is promoted in this scenario and the production of biogas in anaerobic digestion plants was implemented.

In the MI separate collection of biowaste and recyclable materials was irrelevant. An organization of the informal primary collectors did not take place, but there was an extension of the drop-off systems. Mechanical sorting of mixed waste to recover materials for recycling was introduced. Utilization of landfill gas as an energy source was as well promoted.

The results showed that the generation flux of MSW is at least 50% larger in all scenarios in 2030 compared to the year 2007, exceeding the limit value proposed (1.6 kg/(person·day)). The highest value (2.0 kg/(person·day)) is obtained in the MI scenario, and the lowest (1.8 kg/(person·day)) in the CR scenario. Pre-treatment of mixed MSW collected is only achieved in the CR scenario with a value of 18%, however, the target value is not achieved (50%). The highest greenhouse gas emission value is obtained in the MI scenario with 295 kg CO_{2eq}/(person·year), the lowest value of 155 kg $CO_{2\text{-}eq}$/(person·year) is obtained in the CR scenario; a value that is still very high in comparison with the suggested target (71 kg CO_{2eq}/(person·year)). The largest recycling rate is obtained in the CR scenario (43%), which is better than the target value proposed (36%), the lowest recycling rate is obtained in the MI scenario (20%). The income of primary collectors in comparison with the income of one individual household is improved significantly in the CR scenario (128%), in the MI scenario, earnings of primary collectors decreased to 51%. The share of GDP spent on MSW management is lower in 2030, compared to the year 2007, in all scenarios the largest value of 0.17% is obtained in the CR scenario, and the lowest value of 0.14% is obtained in the MI scenario.

The results of the evaluation of the scenarios showed that the largest sustainability deficits are the amount of mixed MSW which undergoes pre-treatment before final disposal in landfill sites, the greenhouse gas emissions associated to MSW treatment and disposal, as well as the share of GDP spent on MSW management.

The results obtained suggested that an integration of several factors is required to increase sustainability. Moreover, it is essential to strengthen and take advantage of the subsystems which are already working within the waste management system, as in the case of the informal sector. In addition to the implementation of flexible treatment technologies which help to decrease negative environmental impacts. Moreover, the costs of these technologies should be affordable, allowing a better financial management.

Keywords: megacities, municipal solid waste management, informal waste sector, sustainability analysis, indicators, scenarios, Santiago de Chile

Zusammenfassung

Megacities lassen sich durch ein starkes Bevölkerungswachstum sowie durch eine hohe Bevölkerungsdichte charakterisieren. Ihr Verbrauch an Ressourcen ist sehr hoch und nimmt ständig zu. Dies führt zur Entstehung von großen Mengen an Siedlungsabfall, deren Sammlung und Entsorgung die Umwelt belastet. Eine geeignete Behandlung dieser Siedlungsabfälle ist entscheidend für die Gesundheit der Stadtbewohner, für den Schutz der Umwelt und damit für eine nachhaltige Entwicklung dieser Städte.

Es ist bekannt, dass ein steigender Lebensstandard das Pro-Kopf-Aufkommen an Siedlungsabfällen erhöht. Die Metropolregion Santiago (MRS) verzeichnete in den letzten Jahren ein großes Bevölkerungswachstum und einen Anstieg des Lebensstandards. Als Folge davon hat sich das Aufkommen von Siedlungsabfällen von 1,8 Millionen Tonnen im Jahr 1995 auf 3,0 Millionen Tonnen im Jahr 2007 erhöht.

In dieser Arbeit wurde der aktuelle Zustand des Abfallmanagements in MRS unter dem Aspekt der Nachhaltigkeit bewertet. Die Bedeutung des informellen Sektors für das Abfallmanagement der Stadt wurde untersucht und bewertet. Zusätzlich wurden unterschiedliche Szenarien für ein zukünftiges Abfallmanagement entwickelt und unter Aspekten der Nachhaltigkeit bewertet.

Die Daten für den aktuellen Zustand des Abfallmanagements wurden durch Feldforschungen, Fragebögen für unterschiedliche Akteure, Feldbesuche und durch eine systematische Auswertung von bereits vorliegender Literatur erhoben. Das integrative Nachhaltigkeitskonzept der Helmholtz-Gemeinschaft diente als konzeptioneller Rahmen für die Studie.

Zur Bewertung des aktuellen Zustands des Abfallmanagements in MRS wurden aus einer Vielzahl von Nachhaltigkeitsindikatoren die für MRS relevantesten identifiziert, deren aktuelle Werte bestimmt und geeignete Zielwerte festgelegt. Das Pro-Kopf-Aufkommen an Siedlungsabfällen (Indikator 1) stieg von 0,8 kg im Jahr 1995 auf 1,2 kg im Jahr 2007. Dieser Wert ist vergleichbar mit Werten in Ländern, die ein deutlich höheres Bruttoinlandsprodukt aufweisen. Die Abfallentsorgung in MRS beruht in erster Linie auf der Ablagerung in Deponien. Es existiert keine Abfallvorbehandlung (Indikator 2), die den organischen Kohlenstoff-Gehalt des zu deponierenden Abfalls reduzieren würde; der aktuelle Wert dieses Indikators ist daher null. Die durch die Deponierung unvorbehandelter Abfälle verursachten Emissionen von Treibhausgasen (Indikator 3) liegen bei 143 kg $CO_{2\text{-eq}}$/Kopf/Jahr. Die Wiederverwertungsquoten (Indikator 4) sind relativ gering und liegen bei 14 %. Es existiert keine energetische Verwertung von Abfällen. Die gegenwärtigen Wiederverwertungsquoten können nur wegen der umfangreichen Arbeit der informellen Müllsammler erreicht werden. Die von den Kommunen organisierte Sammlung und Trennung von Wertstoffen (formeller Sektor) ist von untergeordneter Bedeutung. Als weiterer relevanter Indikator wurden die Kosten des Abfallmanagements im Verhältnis zum Bruttoinlandsprodukt herangezogen. Der aktuelle Wert für diesen Indikator beträgt 0,22 % (US$ 17/Kopf/Jahr).

Ein Vergleich der aktuellen Werte mit den festgelegten Zielwerten zeigt, dass die größten Nachhaltigkeitsdefizite des derzeitigen Abfallmanagements in MRS darin liegen, dass nahezu die gesamte Abfallmenge ohne jegliche Vorbehandlung deponiert wird. Damit verbunden sind lang andauernde Emissionen von Treibhausgasen, die einen Einfluss auf das globale Klima haben.

Um herauszufinden, ob und wie der informelle Sektor im Abfallmanagement zur Nachhaltigkeit beiträgt, wurden die von verschiedenen Organisationen gesammelten und in Zeitungen und Fachzeitschriften veröffentlichten Erfahrungen mit informellen Müllsammlern

in Lateinamerika analysiert. Dabei wurden die entsprechenden Akteure sowie etablierte Allianzen zwischen diesen Akteuren identifiziert. Schlüsselfaktoren für ein nachhaltiges Abfallmanagement unter Einbeziehung des informellen Sektors sind unter anderem die Legalisierung der Schattenwirtschaft, feste Verträge mit Partnerunternehmen über die Abnahme der Sekundärrohstoffe und ein weiterer Ausbau der Tätigkeiten des informellen Sektors bis hin zur Produktaufbereitung. Relevante Akteure für die Gestaltung der Arbeitsbedingungen des informellen Sektors sind Vertreter privater und öffentlicher Unternehmen, einzelne gesellschaftliche Gruppen sowie Vertreter von Nichtregierungsorganisationen.

Schließlich wurden drei explorative Szenarien für das Bezugsjahr 2030 entwickelt: *Business as Usual* (BAU), *Collective Responsibility* (CR) und *Market Individualism* (MI). Dabei wurde, abgeleitet aus den übergeordneten allgemeinen Rahmenbedingungen der einzelnen Szenarien, die Entwicklung des Abfallaufkommens und der Abfallzusammensetzung bis zum Jahr 2030 abgeschätzt, und unterschiedliche organisatorische und technische Optionen der Behandlung, Verwertung und Entsorgung von Abfällen berücksichtigt.

Das BAU-Szenario enthält eine getrennte Sammlung von Bioabfall und von Wertstoffen; hervorgerufen durch einen verstärkten Organisationsgrad der informellen Müllsammler und den Ausbau von Bring-Systemen im formellen Sektor. Die Errichtung mechanischer Sortierungsanlagen für gemischten Abfall trägt zur Verwertung der Materialien und zum Recycling bei. Das entstehende Deponiegas wird als erneuerbare Energiequelle genutzt. Darüber hinaus wird in Vergärungsanlagen Biogas erzeugt und ebenfalls energetisch genutzt.

Das CR-Szenario enthält ebenfalls eine getrennte Sammlung von Bioabfall und Wertstoffen. Dies wird erreicht durch eine verstärkte Zusammenarbeit mit den jetzt organisierten Müllsammlern und durch den Ausbau von Bring-Systemen im formellen Sektor. Mechanische Sortierungsanlagen für gemischten Abfall tragen zur Verwertung von Materialien und zum Recycling bei. Durch Abtrennung einer heizwertreichen Fraktion in mechanisch biologischen Anlagen werden Sekundärbrennstoffe produziert, die in Zementwerken für die Feuerung eingesetzt werden können. Darüber hinaus werden, wie im BAU-Szenario, das entstehende Deponiegas sowie das in Vergärungsanlagen erzeugte Biogas energetisch genutzt.

Im MI-Szenario sind Wiederverwertungsstrategien von untergeordneter Bedeutung. Die getrennte Müllsammlung ist vernachlässigbar. Es gibt kein Interesse an einer Zusammenarbeit mit den informellen Müllsammlern und keine Anreize für einen verstärkten Organisationsgrad in diesem Bereich. Deshalb bleibt die Branche weitgehend informell. Technologische Entwicklungen in diesem Szenario enthalten die mechanische Sortierung von gemischtem Abfall und die energetische Verwertung von Deponiegas.

Die Ergebnisse zeigten, dass das Pro-Kopf-Aufkommen an Siedlungsabfällen im Jahr 2030 in allen Szenarien deutlich höher als im Jahr 2007 ist und der festgelegte Zielwert von 1,6 kg/Kopf/Tag nicht erreicht wurde. Den höchsten Wert (2,0 kg/Kopf/Tag) weist das MI-Szenario auf, der niedrigste Wert (1,8 kg/Kopf/Tag) wurde im CR-Szenario gefunden. Eine Vorbehandlung der gesammelten gemischten Siedlungsabfälle findet nur im CR-Szenario statt, der entsprechende Wert beträgt 18 %, der Zielwert von 50 % wird damit nicht erreicht. Die höchsten Treibhausgasemissionen treten im MI-Szenario (295 kg $CO_{2\text{-eq}}$/Kopf/Jahr) auf, den niedrigsten Wert (155 kg $CO_{2\text{-eq}}$/Kopf/Jahr) findet man im CR-Szenario. All diese Werte sind, verglichen mit dem festgelegten Zielwert von 71 kg/Kopf/Jahr, deutlich zu hoch. Der Zielwert für die Wiederverwertungsquote (36 %) wurde im CR-Szenario erreicht (43 %), den niedrigsten Wert zeigt das MI-Szenario (20 %). Die Zielwerte für das Einkommen der Müllsammler (100 %) wurden im CR-Szenario erreicht (128 %). Im MI-Szenario beträgt dieser Wert lediglich 51 %. Die Kosten für das Abfallmanagement im Verhältnis zum Bruttoinlandsprodukt sinken in den drei Szenarien. Den höchsten Wert weist das CR-Szenario (0,17 %) auf und den niedrigsten Wert das MI-Szenario (0,14 %).

Die Ergebnisse der Szenario-Bewertung zeigten, dass die wichtigsten Nachhaltigkeitsdefizite in der vorbehandelten Abfallmenge und in den damit verbundenen Treibhausgasemissionen liegen. Ein weiteres Defizit, das in den drei Szenarien sichtbar wurde, sind die Kosten für die Abfallwirtschaft im Verhältnis zum Bruttoinlandsprodukt.

Aus den Ergebnissen lässt sich ableiten, dass ein Einbeziehen von mehreren Faktoren erforderlich ist, um die Nachhaltigkeit des Abfallmanagementsystems in den drei Szenarien zu steigern und dass es von wesentlicher Bedeutung ist, schon vorhandene und gut funktionierende Subsysteme, wie das der informellen Müllsammler, zu nutzen und zu stärken. Ebenso ist die Umsetzung robuster Behandlungstechnologien, die einen Beitrag zur Reduktion negativer Umweltauswirkungen leisten, zu forcieren. Diese Technologien sollten preiswert sein, um ihren Einsatz auch unter wirtschaftlich vertretbaren Gesichtspunkten zu ermöglichen.

Stichworte: Megastädte, Abfallwirtschaft, informeller Sektor, Nachhaltigkeitsanalyse, Indikatoren, Szenarien, Santiago de Chile

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Abbreviations

ARB	*Recicladores de Bogotá* Waste Recyclers of Bogotá
ANR	*Asociación Nacional de Recolectores* National Collectors Association
ASRI	*Asociación de Recolectores Independientes* Union Association of Independent Collectors
AREILS	*Asociación de Recolectores Ecológicos Independientes de La Serena* Independent Ecological Collectors of La Serena
BAU	Business as Usual
CDM	Clean Development Mechanisms
CHP	Combined heat and power
CMPC	*Compañía Manufacturera de Papeles y Cartones* Manufacturing Company of Paper and Cardboard
CONAMA	*Comisión Nacional del Medio Ambiente* National Commission of Environment
CR	Collective Responsibility
GDP	Gross domestic product
GHG	Green house gas
GTZ	*Deutsche Gesellschaft für Technische Zusammenarbeit* German Technical Cooperation Association
GWP	Global Potential Units
GORE	*Gobierno Regional* Regional Government
RHM	Risk Habitat Megacity Project
ISC	Integrative Sustainability Concept
KDM	Kenbourbe Environmental Engineering KIASA
KrW-AbfG	*Kreislaufwirtschafts- und Abfallgesetz* Act for Promoting Closed Substance Cycle Waste Management and Ensuring Environmentally Compatible Waste Disposal
LFG	Landfill gas
MBT	Mechanical biological treatment
MFA	Material flow analysis
MI	Market Individualism
MNRCH	*Movimiento Nacional de Recolectores de Chile* National Movement of Recyclers of Chile
MRF	Materials recovery facility
MRS	Metropolitan Region of Santiago de Chile
MSW	Municipal solid waste
MTU	Monthly Tax Unit
NCV	Net calorific value
NGO	Non Governmental Organization

OECD	Organisation for Economic Co-operation and Development
RDF	Recovered derived fuel
SEIA	*Sistema de evaluación de impacto ambiental* Environmental Impact assessment system
Seremi Salud	*Secretaria Regional Ministerial de Salud* Regional Ministerial Health Secretary
SRF	Solid recovered fuel
SUBDERE	*Secretaría de Desarrollo Regional* Secretary of Regional Development
TOC	Total organic carbon
UN	United Nations

Symbols

Latin Symbols

BM	biodegradable organic matter	[%]
CV	calorific value	[MJ/m³]; [MJ/kg]
C_c	capital costs	[Euro]
C_o	operation costs	[Euro]
C_0	total organic carbon	[kg_{carbon}/Mg_{waste}]
C_p	production costs	[Euro]
$C^{GDP}{}_{MSW}$	costs of MSW management expressed as share of the GDP	[%]
C_{MSW}	total costs of MSW management	[US$]
CV	calorific value	[MJ/kg]
D	degradation degree	
D_n	waste treatment plant design capacity	[Mg/year]
EF	emission factor of GHG	[kg /Mg]; [kg/TJ]
Em	Emissions of GHG	[Mg $CO_{2\text{-eq}}$/year]
Em_A	avoided emissions of GHG	[Mg $CO_{2\text{-eq}}$/year]
Em_P	produced emission of GHG	[Mg $CO_{2\text{-eq}}$/year]
e_{elec}	electricity price	[Euro/kWh]
e_f	oil fuel price	[Euro/l]
f	frequency of collection	[times/week]
$F_{v\text{-}m}$	factor to transform volume of methane to mass (normal conditions)	
FC	fossil carbon content	[%]
GDP	gross domestic product	[US$]
GWP	global warming potential units	[$CO_{2\text{-eq}}$]
G_e	landfill gas production potential	[Nm^3/Mg_{waste}]
G^*_t	landfill gas production in a given time t	[Nm³/year]
$G^*_{s,t}$	specific landfill gas production until time t	[Nm³]
g	parameters affecting MSW generation flux	
h	specific enthalpy	[MJ/kg]
k	methane generation rate constant	[$year^{-1}$]
M^*	waste mass flow	[Mg/year]
m^*_j	waste mass flow treated or disposed with method j	[Mg/year]
M	mass flux	[kg/(person·year)]
NCV	net calorific value	[MJ/kg]
N	number	
N_{IW}	number of informal waste pickers	
Q	heat flux	[MJ/kg]
Q^*	heat flow	[MJ/year]

T	temperature	[°C]
TC	transfer coefficient	
t	time	[year]
$t_{0.5}$	half life time	[year]
V	volume	[m^3]
W_d	working days of waste pickers	[days/year]
w	water content	[%]
w_{tech}	annual average wages for a technical employee	[Euro/month]
x_{CH4}	share of methane in landfill gas	% v/v

Greek symbols

α	burn-out rate, it describes the actual carbon conversion during combustion	[-]
ρ	density	[kg/m^3]
$\varepsilon^{collection}$	collection efficiency of landfill gas	[%]
ε_{be}	efficiency of electricity generation by biogas combustion	[%]
ε_{pp}	power plant efficiency	[%]
ε	energy (thermal or electrical) generation efficiency	[%]
θ	economic overhead and benefits	

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A	(emissions) avoided
AD	Anaerobic digestion
B	biowaste
CP	composting process
c	collected
FF	fossil fuel
L	disposal at landfills
MBT	mechanical biological treatment
MSW	municipal solid waste
P	(emissions) produced
RDF	recovered derived fuel
RM	recovery of materials
R-DO	recovery by drop off systems
R-SC	recovery by segregated collection
R-IS	recovery by informal collection
R-wte	recovery by waste to energy
T	treatment
wte	waste to energy

Chapter 1
Introduction

1.1 Problem Definition

Rapid urbanization processes are a remarkable characteristic of the 21st century. According to the estimations of the United Nations (UN) (UN 2008) in the year 2008 for the first time in history, more people were living in urban habitats than in rural ones. Latin America has witnessed a rapid growth in population, with an accelerated move towards urbanization. About 78% of the total population lives in urban settlements there (UN 2008), a level that compares with that of Europe (76%) and which is higher than in Asia (41%) and in Africa (38%).

The UN estimates that the fraction of urban inhabitants in Latin America and the Caribbean will increase to 85% by the year 2030. Cities in Latin America share similar characteristics because of their similar evolution circumstances. Limited employment opportunities and marginal livelihood led to extreme migration from rural to urban areas (ECLAC/CEPAL 2000), creating *large* and *mega* urban agglomerations that concentrate a population of at least five and ten million inhabitants, respectively. These large urbanizations concentrate in general more than half of the national population. Urban-based economy activities account for more than 80% of the gross domestic product (GDP) in those Latin American countries with the largest urbanization rates. Additionally, Latin America urban habitats suffer from social-spatial differentiation (De Mattos 1999), unequal distribution of resources, rapid changes of land use management and expansion, inadequate transport and air pollution (ECLAC/CEPAL 2000) and are centers of unequal income distribution.

Urban habitats are traditionally engines of social modernization, global economic growth and providers of opportunities for social and human capital development, but megacities are as well spaces of risks with a complex variety of simultaneous and interacting processes (Heinrichs et al. 2008). Cities face a multitude of problems, specially associated with globalization. According to the UN, five comprehensive problem fields are relevant for the enhancement of social and economic conditions within cities: shelter, society, environment, economy, and governance (UN 2004). Within the environmental aspect, one key challenge is the management of municipal solid waste (MSW).

1.2 Municipal Solid Waste Management in Latin America

An environmental consequence of the process of urbanization in Latin America is the generation of large quantities of MSW, which has to be collected, treated, and disposed of appropriately. The solid waste generation rate in Latin American countries varies from 0.4 to 2.0 kg/(person·day) (PAHO 2005). The large cities are the biggest waste producers, with approximately 1.0 kg/(person·day) . On the other hand, the small settlements generate an average of 0.5 kg/(person·day) . Within the vast urban areas of Latin America, Sao Paolo had the highest per capita waste production in 2005, with a value of 2.0 kg/(person·day) , which is comparable to waste generation in industrialized and high income countries such as Luxembourg, Switzerland or Ireland (OECD 2007). However, whereas in these countries the waste management has evolved together with the increase in waste production, the rapid urbanization characteristic of megacities in Latin America has not left enough time for planning adequate infrastructures, development of competent governmental institutions and policies related to MSW management.

Several countries in Latin America have governmental institutions to coordinate waste management actions. At the national level, in general the health and/or environment ministries provide the functions related to waste management. At the local level, the municipalities traditionally have the responsibility for the management of the residues produced within theirs jurisdiction. The service can be accomplished in a publicly organized way, or using private organizations and entities by means of concessions given in public bids.

Information on recycling coverage in Latin America is limited, because of the absence of records about the amount and type of materials recycled. This can be attributed to the fact that a publicly organized segregate collection of recyclable materials and biowaste is not carried out on a large scale. On average, only 2.2% of the produced waste is formally recycled (PAHO 2005). In contrast, informal recycling widely takes place in the region. This is a distinctive characteristic of the waste management in low and middle income countries, where usually a group of people earn their livelihood by collecting, sorting and trading valuable materials obtained at collection and final disposal sites, which are used as secondary raw materials by production industries (Medina 2008). The informality of the sector makes it difficult to have accurate information about the magnitude of their exact contribution to recycling.

The MSW management field is considered in the majority of Latin American countries, in the best case, as part of the water and sanitation sector (PAHO 2005). Investments in the area are minimal compared with other public services, such as electricity or water, and focus for the most part on the purchasing and requirement of collection vehicles and infrastructural systems for final disposal in landfills or dumping sites.

Summarizing, although health and environmental problems arising from inadequate MSW management are well known, most countries in Latin America have not given this field the necessary weight. Nor has the development of services related to waste management received sufficient attention. Against this background, it seems a big challenge to find sustainable solutions to handle the large amounts of MSW generated, if negative impacts on health, on the well-being of urban residents and on the environment are to be avoided, without leaving aside the informal primary collectors.

The Risk Habitat Megacity Project[1], in which the present research work is embedded, selected the Metropolitan Region of Santiago (MRS), the center of one of the most urbanized countries in Latin America, as anchor city. This project investigated several fields such as land use management, socio-spatial differentiation, energy systems, transportation, air quality and health, water resources and services, and waste management, which is the focus of the present research work. The city was chosen on the one hand, because it is characterized by representative problems often associated with megacities in Latin America (Rehner and Jordan 2009); on the other hand, because this urban agglomeration offers an excellent research infrastructure and research partners with international recognition. Moreover, Santiago de Chile presents large potential improvements in the MSW management area, and the comparatively homogenous culture across Latin America favors both the transferability and dissemination of results.

1.3 Research Goal and Research Questions

The objectives of the present research work are influenced by the fact that in Latin American megacities, and specifically in Santiago de Chile, the municipal solid waste management has been developed with an incomplete vision, understanding it basically as a problem related to service, disregarding its environmental, social, economic and health components. Therefore, the goal of the present thesis is to evaluate the current MSW management system in Santiago de Chile under the view of sustainable development. Moreover, in order to implement

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[1] For more information on the Risk Habitat Megacity Project refer to: http://www.risk-habitat-megacity.ufz.de/; (Bräutigam et al. 2008, Henrichs and Nuissl 2008, Kopfmüller et al. 2009)

appropriate practices of treatment, recovery, and disposal, considering the participation of the informal sector, alternative MSW management scenarios for the year 2030 are evaluated under a sustainability point of view. In relation to the achievement of this goal, several questions need to be investigated:

1. How sustainable is the current MSW management?
2. What is the role of the informal waste sector?
3. Does the integration of the informal sector have positive effects on sustainable development?
4. What technical systems can be implemented in order to improve the sustainability of the MSW management system?
5. How can a more efficient participation of the informal sector in the technical systems of MSW management be achieved?

The approach implemented to answer these questions is based on the use of sustainability indicators for MSW management. Through literature review and own field research, values are obtained for the current situation. On the basis of this analysis, different scenarios for waste management for the year 2030 are developed and the corresponding values of the selected sustainability indicators are evaluated. The Integrative Helmholtz Sustainability Concept (Kopfmüller J. et al. 2001) serves as foundation for the development of the sustainability assessment.

The outcome and recommendations of the present research are an attempt to address the sustainability deficits of the MSW management in Santiago de Chile, as well as the related threats to the achievement of the sustainable development of this large city.

1.4 Thesis Outline

Related literature on MSW management systems is provided in Chapter 2. The topics include the functional elements of MSW management, with a brief description of the informal waste sector role. Additionally, a description of the system used to evaluate the sustainability of the solid waste management in Santiago de Chile is provided.

The research methodology is described in Chapter 3, where the research system is defined, as well as the set of sustainability indicators used in the assessment of the current and future waste management options. The methodology approach used to develop the future scenarios of MSW management is also given in Chapter 3.

The MSW management situation in Santiago de Chile, which is the subject of the present research, is described in Chapter 4. Most of the information given in this Chapter is the result of an extensive literature review and own field research carried out in Santiago de Chile. A small review about the country is given, followed by a description of the functional systems of the MSW management in the city, including technical, financial and institutional aspects.

The sustainability assessment of the current system is presented in Chapter 5. The topics discussed include the impacts of the current indicator values and their threats to the achievement of sustainability.

In Chapter 6, the role of the informal sector in the MSW management of Santiago de Chile as well as its impacts on sustainable development are discussed. Options for inclusion based on Latin American experiences are presented.

The developed explorative scenarios for the future management of solid waste in Santiago de Chile, together with the evaluation of sustainability, are presented and discussed in Chapter 7.

Finally, key findings and their consequences are summarized in Chapter 8.

Chapter 2

Literature Review

This Chapter provides an overview of the subjects relevant to this research, including a description of the general functional elements of solid waste management. Some illustrate examples for the situation in Latin America and other developing regions are given. Because the informal sector plays an important role in waste management in Latin America, background information about this sector is summarized. Finally, the sustainability concept chosen for the evaluation is briefly described.

2.1 Solid Waste Management

According to the *Act for Promoting Closed Substance Cycle Waste Management and Ensuring Environmentally Compatible Waste Disposal* ("Kreislaufwirtschafts- und Abfallgesetz – KrW-AbfG") (BMU 1994) waste means "all movable property which the holder discards, or intends or is required to discard. 'Waste for recovery' is waste that is recovered; waste that is not recovered is 'waste for disposal'".

Accordingly, solid waste management corresponds to the processes and technologies applied to achieve the objectives of waste management, namely a) to safeguard public health, by preventing the spread of disease, b) the protection of the environment and c) the conservation of resources and energy. Solid waste management has evolved in its approach from being only a sanitary concern to include legal, technical, institutional, financial, environmental and socio-cultural aspects.

In its widest sense, the activities associated with the management of solid waste from its generation to final disposal include collection and transport, treatment, recovery and final disposal. These functional elements are closely interconnected (Figure 2.1), but they are not necessarily presented in every MSW management system. In most low and middle income countries, the system is limited to waste generation, handling at the source, collection and disposal at landfills, in the best case. On the contrary, in most of the industrial countries, every functional element is, as a rule, found within the system.

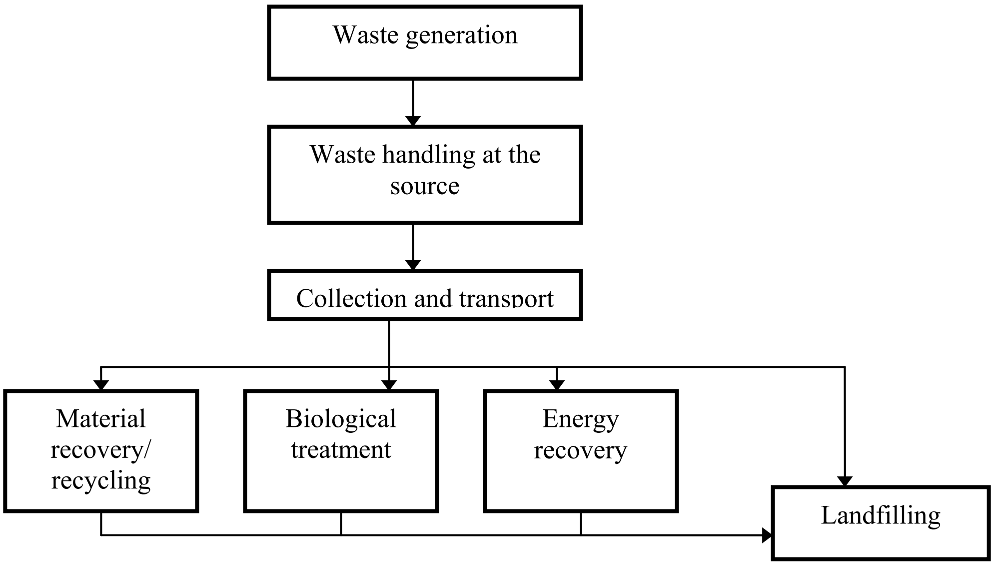
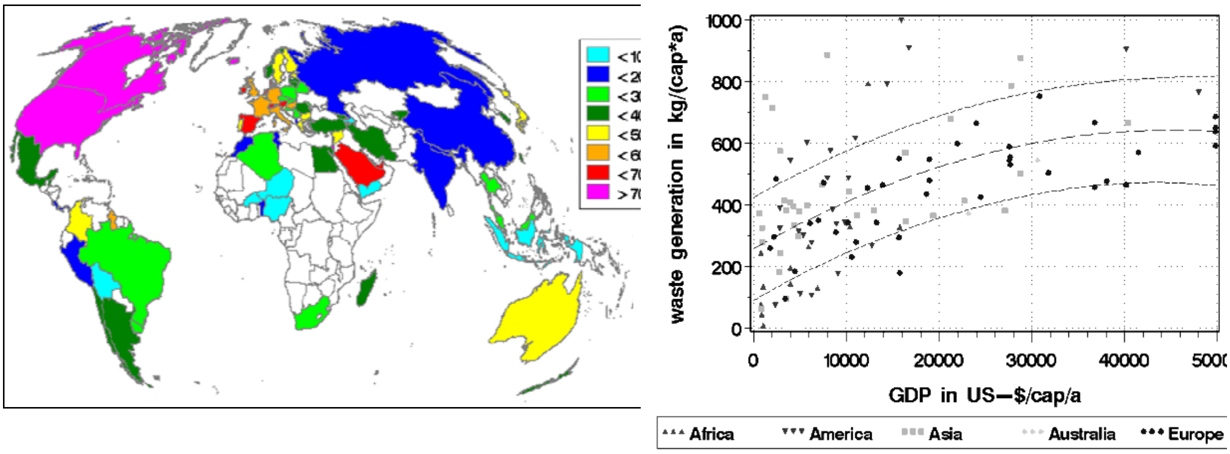


Figure 2.1 Functional elements of solid waste management (based on Seifert 2006a)

2.1.1 Solid waste generation

Waste is generated by activities in all economic sectors. Inefficient use of resources, low durability of goods and unsustainable consumption patterns contribute to more solid waste generation (EEA 2002). Additionally, several studies suggest (Beigl 2003, Vehlow 2008b, 2010) that there is some relationship between waste generation per capita and the economic development of a region. In Figure 2.2, waste generation data from selected countries is compiled; data varies from annual values below 100 kg in poorest countries to values above 700 kg in richer ones. Economic development and the growing of urbanization are in general associated with changes in consumption patterns, rising quality of life and rising rates of resource consumption, which in turn increase rates of waste production. For this reason, large urban areas are struggling with the problems of high waste quantities, associated environmental impacts and costs involved for treatment and disposal.



a) b)

Figure 2.2 **(Vehlow 2008a, 2010)**
a) Waste generation in selected countries
b) Waste generation vs. GDP

2.1.2 Waste handling at the source

This functional element encompasses activities associated with the management of waste until it is located in storage devices for further collection, including the transport of the storage containers to the collection point. The handling of solid waste at the source is a very important step in MSW management. For instance, separation of different waste fractions reduces the contamination potential of materials that can be reused, recovered or recycled.

Waste handling at the source includes backyard or home composting, which avoids the adverse environmental impacts generated from the transport of residues to biological treatment plants. Additionally, this practice diverts materials from landfills, extending their lifetime and reducing the expenses and environmental impacts associated with landfilling (Tchobanoglous and Kreith 2002).

On-site storage is of primary importance regarding aesthetic aspects, public health and safety, which is an aspect not yet achieved in many low and middle income countries. Degradation of the biogenic fraction of solid waste leads to the production of odors and depending on the extent of the storage time, rodents, insects and pathogen might appear and spread disease. Therefore, it is necessary to use resistant and adequate containers for on-site storage. Moreover, the type and capacity of containers to be used depend on the specific characteristics of the waste, the collection system and frequency, and the space available for the placement of containers (Tchobanoglous and Kreith 2002).

High income cities often employ a combination of civic commitment, environmental awareness, public education, law and enforcement to support separation practices and separate collection procedures (Oskamp et al. 1991). On the other hand, this motivation and the capacity to provide suitable incentives in cities in low and middle income countries is usually weak. Practices of handling waste at the source require the development of incentives and the education of waste generators.

2.1.3 Waste collection and transport

This functional element includes the gathering and transport of mixed and/or separate solid waste to the emptying point. This location includes separation plants, treatment or energy recovery facilities, transfer stations, or landfill sites (Tchobanoglous 1993). Collection of solid waste is a key element within the solid waste management system. It is generally the most costly subsystem in developing regions, representing about 60% to 80% of the total waste management costs (Bilitewski et al. 1997, UNEP 2005). Hence, efficiency improvements in the current waste collection services bring about overall savings. Experience has shown that private sector is 20% to 40% less expensive than publicly organized services (UNEP 2005), and privatization could facilitate the entry of micro and small enterprises to provide these services. Moreover, collection and transport of waste are one of the more visible signs of a proper waste management system. Inappropriate and insufficient collection services cause litter, uncontrolled dumping sites and poor public sanitation.

Collection methods can be classified in drop-off and curbside systems:

1. Drop-off systems: the mixed or pre-sorted waste is taken by the producers to central location points. These containers are emptied by the municipality or private institutions. In Europe, this method is well established, particularly to collect glass and other recyclable materials (Gallenkemper et al. 2010). However, in low and middle income countries, containers that are open to the public are usually dirty and unhygienic. Animals and people from the informal sector might search for recyclable materials, spreading the waste around. If organic residues are collected through this method, and depending on the storage time, decomposition occurs, generating bad odors, attracting rats and flies (Herrle et al. 2005). On the other hand, this is an inexpensive method that works even in areas of difficult access.
2. Curbside collection: in this system the waste is collected door-to-door by municipalities or private companies. Users are, as a rule, charged for this service, but the related feeds and the charging systems differ widely within regions.
   In low and middle income countries, another curbside alternative consists of collection with non-motorized systems (Medina undated). In this case, waste is transported from the source with simple vehicles (hand or animal drawn carts, bicycle, tricycles, etc.) The capacity of the system is limited and routes are adapted to transport used. This system contributes to jobs creation and income opportunities.

2.1.4 Materials recovery/ Recycling

Recycling is the substitution of raw materials through extraction of substances from waste, returning them into the economic cycle. Recycling techniques have gained more relevance in recent decades because of growing environmental awareness in industrial countries and the knowledge about limitations in availability of primary raw materials.

The design of materials recovery facilities (MRF) varies from low to high tech. In low technology plants, a large part of separation and sorting is performed by hand. Modern material recovery plants consist of a series of mechanical processes, which have evolved together with waste flows complexities. High tech recycling processes usually combine more than one operation units (Table 2.1).

Table 2.1 Recycling processes (Pretz 2008, Pretz 2010)

Process	Function	Equipment
Crushing	Reduction of grain size	Rotor sheer High torque shredder One shaft shredder
Sieving	Separation according to particle size	Drum screen Star screen Flip – flop screen
Sorting	Separation due to physical and chemical conditions	Magnetic conditions: Magnetic separators Electrical conductivity: Eddy current separators Density and shape: Air classifier, air table Durability and size: Paper sorters, paddle sifter Chemical composition on surface: NIR-sorters Color: Color separators Density: X-Ray separators

These processes are arranged according to the goals of the plant. The number of processes depends on the complexity of the waste streams and on the desired quality of the products. Usually, high recovery rates are accompanied with low quality and vice versa (Pretz 2008).

Figure 2.3 displays a simplified flow sheet for a low technology plant. In the first step, waste bags are opened and fed to the mechanical treatment. There, the material is separated according to its particle size; the coarse fraction contains usually the main share of recyclable materials. Ferrous metals are removed from the waste with magnets, and the recyclable fractions are separated by hand picking classification.

A higher technology plant is depicted in Figure 2.4. After separation by particle size, the coarse fraction is shredded and sent back to the separation drum. Ferrous and non-ferrous metals are removed from the light fraction with magnets or eddy current separators. Then, the materials are sent to a ballistic separator, where one material stream is separated into two fractions, a “rolling heavy fraction” (woods, massive plastic parts) and a “flat light fraction” (foils, textiles, paper, cardboard). Further separation is achieved by waste hand picking.

Numerous mechanical processes established in industrialized countries depend extensively on the delivery of relatively well separated waste fractions as a feed stream. This practice is not yet institutionalized in most low and middle income countries. Additionally, high mechanized technology systems tend to be very expensive and difficult to be implemented in developing countries (UNEP 2005).

As Table 2.2 shows, the low tech MRF has lower capital costs in comparison to automatic classification; however its labor costs are higher. Data given in Table 2.2 is based on German inversion costs.

Table 2.2 Costs comparison between material recovery facilities (Plant capacity $350 \cdot 10^3$ Mg/year) (Lambertz 2009)

Type of plant	Capital costs [million Euro]	Operation costs [Euro/Mg]
Manual	30	25
Automatic	37	12

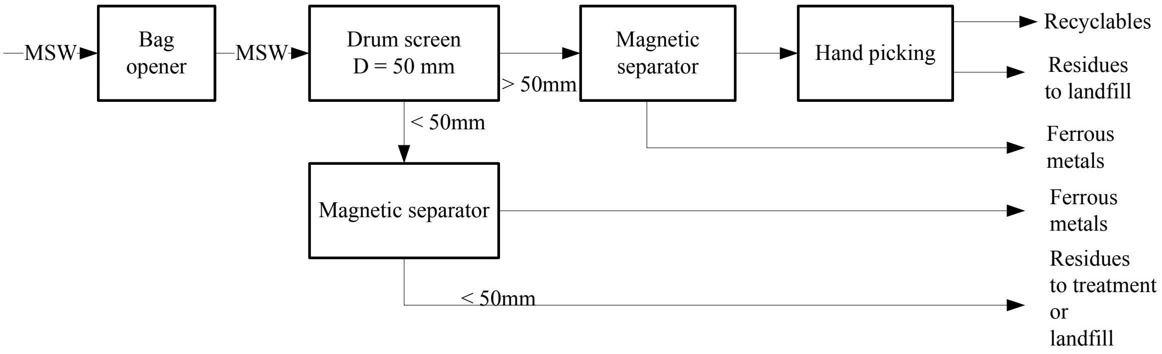


Figure 2.3 Low tech plant - Flow diagram (based on Lambertz 2009)

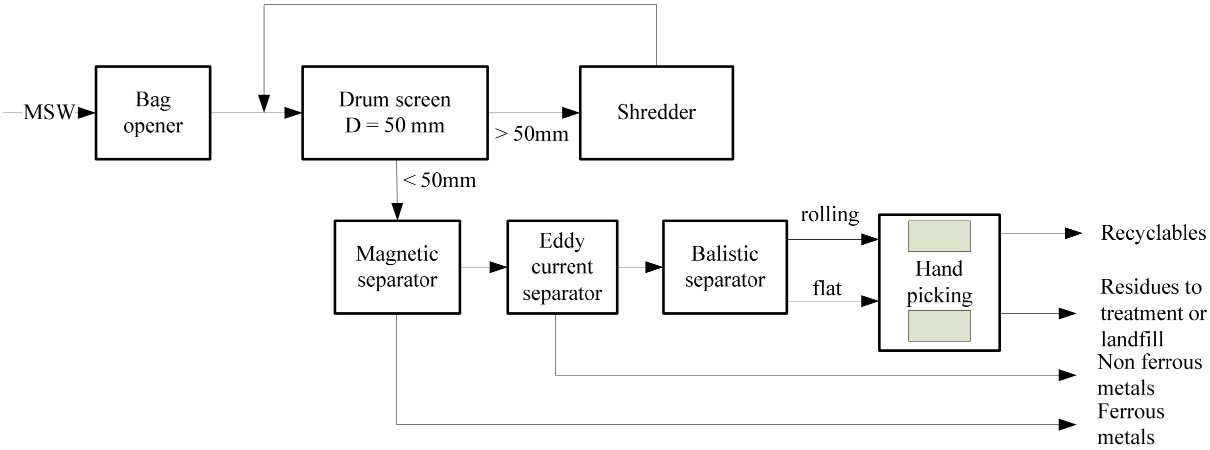


Figure 2.4 Semi automatic plant - Flow diagram (based on Lambertz 2009)

Recovery of resources presents several ecological advantages. It reduces the pressures on natural resources, cumulative environmental pollution, and degradation of the environment associated with manufacturing of products from virgin materials, which are often larger than the environmental impacts of manufacturing the same products from secondary raw materials (Petts 1999). Furthermore, the amount of waste sent to landfills is reduced and hence the operation lifetime of landfills is extended.

Even with stable markets and convenient programs, public education is a critical component to increase the amount of materials to be recycled. Recycling requires the participation of consumers, by purchasing recyclable products, and by companies in using secondary raw materials in their production processes and designing new products which are easier to disassembly or separate (Tchobanoglous 1993).

Recycling markets

The growth of markets for recyclable materials takes place in part as a consequence of policy incentives, but also to general market conditions. The development of such markets could be induced by public authorities through measures in collection schemes and by economic instruments. Consumer education and the incorporation of MSW issues in school curriculum are highly desirable. Externalities, such as environmental benefits of recycling, should be included in the costs of MSW management in order to make recycling systems economic competitive, against final disposal at landfills (OECD 2006). At the local level, some infrastructure is essential, including drop-off centers, and implementation of separate collection. Once materials are collected, processing facilities are required to return the collected materials to a usable form (UNEP 1996).

Secondary material markets and recovery schemes are, according to the World Bank, well established in most developing countries, but they are usually located in the informal economy, consisting on scavengers, micro and small enterprises or community based organizations (Wilson et al. 2001). Because formal segregation and recovery of recyclable materials is not carried out at a large scale in Latin America, the use of complete mechanized material recovery facilities is not very common either (PAHO 2005).

Most MRF in Latin American are stock centers where materials are separated and classified manually. In some cases like in Manizales, Colombia recyclable materials are used in the production of handicraft paper or plastic hoses. Equipment usually found are conveyor belts and compacting machines (Pizarro 2005).

2.1.5 Biological waste treatment

In biological waste treatment, living micro-organisms decompose the biogenic fraction of waste, into water, carbon dioxide (CO_2), methane (CH_4), or aldehydes and acids (EU 2006). The main biological waste treatments include aerobic and anaerobic processes (Figure 2.5).

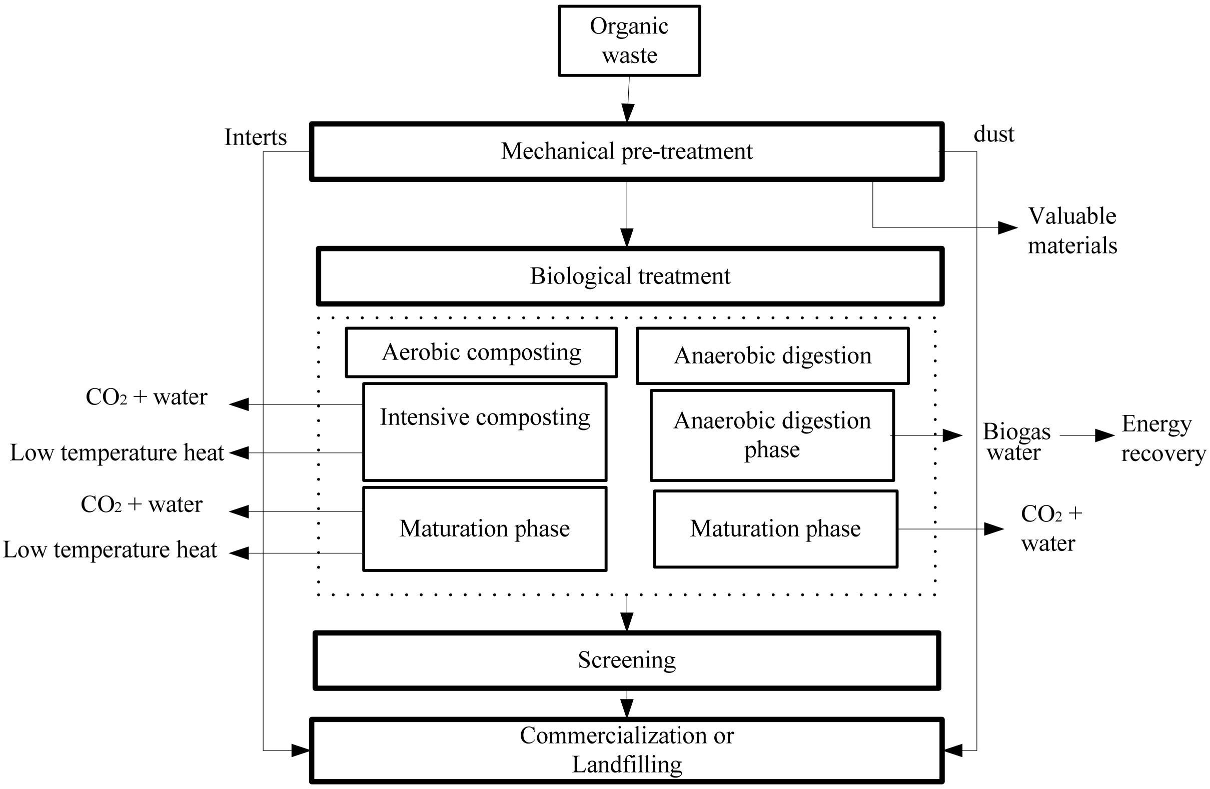


Figure 2.5 Main process steps in biological waste treatment (based on Seifert 2006a, Hagenmeyer 2009)

2.1.5.1 Composting

Composting is the controlled decay of organic matter presented in municipal solid waste, sewage sludge or agricultural biomass, under aerobic conditions, in a warm and moist environment by the action of bacteria, fungi and other organisms (Tchobanoglous 1993). Separated biowaste and yard waste from gardens and public parks are often the main feed streams to composting plants. The separate collection of the biowaste is fundamental to ensure a high quality of the final compost. Experiences in several countries have shown that compost produced using mixed waste as feed material is largely contaminated with heavy metals (UBA 2003a). The main process product is compost, used for agricultural activities or horticultural processes. When done correctly, the final compost becomes a useful product capable of increase soil nutrient level and organic matter in the soil.

Composting in the developing world

In low and middle income countries, usually, more than 40% of the total MSW consists of organic material (UNEP 2005, Vehlow 2008b). It is therefore, theoretical ideal for reduction through composting, decreasing the amount of waste to be landfilled. Nevertheless, composting has not been significant successful or widespread in practice throughout the developing world. Major challenges relate with the need of developing a stable and reliable market for the compost, to guaranty its quality and quantity as well as to secure a sufficient supply of quality biowaste. Additionally, in many developing countries, more attention has been given to improve collection services, than to find alternative solid waste management solutions such as biological treatment (Hoornweg et al. 1999).

In Latin America, composting is usually carried out at the community level. In recent decades, several composting initiatives, with different technical degrees were introduced in the region. However, most of them failed because of inadequate equipment maintenance, inappropriate technology, and lack of markets (PAHO 2005). Nevertheless, there are a few successful cases such as in Montevideo, Uruguay, and in Olinda and in Sao Paulo in Brazil, where composting plants for household organic waste are in operation (PAHO 2005, Hoornweg et al. 1999). In some of these plants, materials recovery takes place. Additionally, in Mexico City one composting plant for the treatment of yard waste is in operation. In Ecuador and Chile, there are experiences of composting with worms applied to household waste (PAHO 2005, personal interview with Sufán, J. 2008).

2.1.5.2 Anaerobic digestion

Anaerobic digestion involves the bacterial decomposition of organic matter in the absence of oxygen (UBA 2003a). The main feed streams include biowaste, organic waste from industries and manure. In comparison to aerobic treatments, anaerobic digestion can be used to treat mixed waste and requires less addition of structural material (UBA 2003a). The products obtained in anaerobic digestion plants include a digestate and an energy rich biogas, constituted mainly of CO_2 and CH_4. The digestate can be used as soil conditioner or fertilizer, and the energy content of the biogas can be recovered in different ways. Digestion techniques can be distinguished based on the operating temperature and the percentage of dry matter in the feedstock.

Anaerobic digestion in low- and middle income countries

Anaerobic digestion has a long tradition in some developing countries such as China and India, predominantly in rural areas for the treatment of animal feces. In Thailand, Nepal and Sri Lanka, implemented anaerobic digestion plants have not operated appropriately. The problems were attributed to poor quality feedstock (caused by inadequate separation of the waste at the source), lack of trained workers to operate the plants and overestimation of biogas production (Müller 2007). In Latin America, there are some anaerobic digestion plants treating wastewater from breweries and sludge, in Colombia for example. In Costa Rica, there are some digestion plants for the treatment of wastewater from coffee production, and in Honduras, an anaerobic plant has been implemented to treat wastewater from palm oil production by using covered wastewater lagoons (Müller 2007).

For the application of anaerobic digestion plants in low and middle income countries, it is important to encourage the development of simple and robust technologies, which can be managed by local workers, particularly in regards of operation, supervision and maintenance of the digester (Vehlow 2008b). Like in composting, it is essential the existence or development of markets for the biological products, public education and environmental awareness campaigns, regarding residues separation.

2.1.5.3 Mechanical biological treatment

Mechanical biological treatment (MBT) includes the application of mechanical steps for material separation and recovery, and biological processes to reduce and stabilize the biodegradable matter. Mechanical biological treatment has been under development in Germany since 1995 (Archer et al. 2005). MBT is neither a single technology nor a complete solution to MSW treatment (Archer et al. 2005, Kranert 2010), it is a generic term describing biological and mechanical processes that are combined in different ways to achieve different objectives:

- Reduction of mass and volume of waste deposited in landfills
- Recovery of materials
- Minimization of environmental impacts from waste deposition in landfills
- Reduction of the complexity of landfill post closure
- Reduction of gas emitted from landfills, in particular the greenhouse gas methane

The feedstock to MBT plants is mixed, unsorted solid waste. In the example displayed in Figure 2.6, the waste is fed to the mechanical treatment prior to the biological treatment; in some instances homogenization of the materials destined to biological treatment is required. Next, materials are separated according to particle size. Some MBT processes result in a mixture of combustible materials (i.e. plastics, textiles, wood) that cannot be recycled, but have a relatively high calorific value, and are generally suitable for co-combustion (Bates 2009). If these residues are prepared from a simple separation of combustibles from MSW they are called *refuse derived fuel* (RDF); when the process has been more extensive they are called *solid recovered fuel* (SRF). These derived fuels are suitable for burning in conventional boiler systems, in fluidized beds or to be used as a source of fuel for electricity-generating systems. Additionally, ferrous and non ferrous metals are also removed. The fine fraction is sent to the subsequent biological treatment, which include aerobic or anaerobic processes. The residues of the biological process are deposited in landfills.

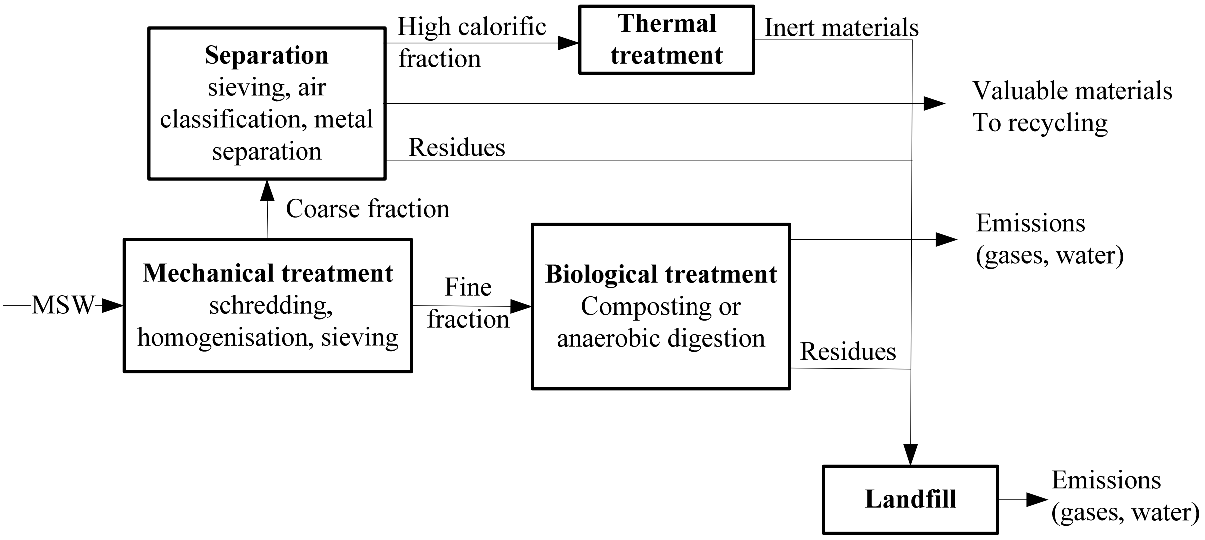


Figure 2.6 Simplified flow sheet of a mechanical biological treatment plant (based on Seifert 2006a, Kranert et al. 2010)

MBT in Latin America

There are some examples, where MBT has been applied successfully in Latin American. In Atlacomulco, Mexico, the goal of the project was the implementation of an integrated and sustainable waste management system, combining a MBT process and the integration of the informal sector in the classification and separation of recyclable materials. The pilot project finished in 2003 (GTZ 2003a, GTZ 2006), but the private company in charge of the MBT process trained personal in Mexico and it is still collaborating with the authorities of Atlacomulco for the waste management in the region.

Another example is the experience of Sao Sebastiao, Brazil. Since 2002, the MSW of the city (approximately 200 Mg/year) is treated in an aerobic MBT plant with the goal of obtaining a stable material to be landfilled (Münnich et al. 2006). This plant improved the quality of life of the informal collectors, who used to work at the landfill, as waste pickers. Many of them are working now sorting marketable materials at a recycling cooperative. This cooperative was organized with the help of the German Development Agency "Deutsche Gesellschaft für Technische Zusammenarbeit" (GTZ), which trained staff in the fundamentals of waste sorting (Münnich et al. 2006).

In Villa Alemana, Chile, a pilot MBT plant was implemented in 2008. The goal of the project was to obtain a biological stable material before landfilling. The Project of Villa Alemana corresponds to a Public-Private Partnership.

The implemented technology has proven to operate successfully in the pre-treatment of waste in these examples, with small modifications of the original process. The main problems corresponded to the high costs of the homogenization step, carried out in rotary drum and spare parts, which are not locally produced and whose maintenance require trained people (Münnich 2009).

2.1.6 Thermal treatment

Combustion is an exothermic process, corresponding to the total oxidation of a fuel. Incineration is the final stage in the chain of chemical reactions taking place between the waste feed into the combustion chamber at ambient temperature and its final combustion temperature. The energy content of waste flows can be recovered by using the heat released in a thermal process. MSW contains typically between 50% and 70% of biogenic energy (Vehlow 2008b) which means that the CO_2 emissions from a waste incinerator can be partly classified as climate neutral. In the European Union, the Waste Incineration Directive makes energy recovery mandatory in all modern waste incineration plants, which are equipped with a boiler and an energy conversion system. The spectrum ranges from total power generation to total heat utilization and possible heat and power combinations (Seifert 2006b).

The most common and well establish waste to energy technology, with more than 100 years of operation, is waste incineration on inclined moving grates (Vehlow 2010). In addition to direct combustion of MSW, it is also possible to co-combust SRF with fossil combustibles in dedicated plants or industrial furnaces, such as power plants or cement kilns.

Novel processes based on combined pyrolysis/gasification have been developed and implemented, in particular in Japan. Gasification and pyrolysis of waste and waste derived fuels are essentially designed as at least two-stage processes with a direct combustion of these products (Besidan et al. 2010). Table 2.3 summarizes the most important characteristics of the process of pyrolysis, gasification and combustion.

The main objectives of MSW incineration include destruction of organic pollutants, volatilization of harmful inorganic waste components and their separation in smaller residue streams, reduction of the waste quantity, conversion of the resulting residues to a form amenable to reuse or land disposal, utilization of the energy inventory and compliance with the respective air emission regulations (Vehlow 2008a, VDI 3640).

Currently, incineration is used as a treatment for a very wide range of residues, including mixed MSW. In principle, a combustion process consists of a major thermal process, a heat recovery step and the multi-stage flue gas cleaning. Figure 2.7 depicts a modern waste incineration plant. A grate system enables self-sustained combustion of untreated waste with lower heating values between approx. 6 and 15 MJ/kg. The illustrated facility includes a grate furnace, boiler and air pollution control system filter, two-stage wet scrubber and catalyst for nitrogen oxides abatement. Often, a charcoal filter or activated carbon injection in front of a fabric filter is installed at the back, for compliance with emissions limits (Vehlow 2008a). The mass flow presented in Figure 2.7 also indicates a material recovery, because a significant fraction of its residues has the potential to be used (Vehlow et al. 2007). Usually, in this type of facilities separation of ferrous and non ferrous metals is performed.

Table 2.3 Basic thermal processes (Seifert and Vehlow 2010)

Parameters	Pyrolysis	Gasification	Combustion
Temperature [°C]	250 - 700	800 - 1400	850 - 1400
Pressure [bar]	1	1 - 50	1
Atmosphere	Inert/Nitrogen	Oxygen, water, air	Oxygen, air
Stoichiometry	0	<1	≥ 1
Gaseous products	Hydrogen, carbon monoxide, hydrocarbons	Hydrogen, carbon monoxide, methane, carbon dioxide	Carbon dioxide, water
Solid products	Ash, coke	Slag	Ash, slag

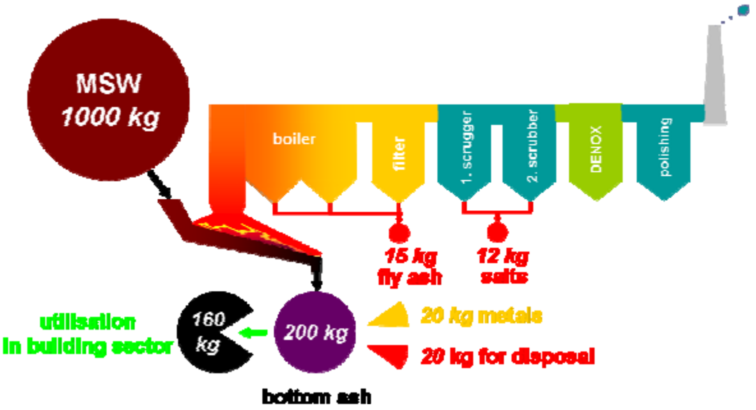


Figure 2.7 Scheme of a waste incinerator with grate furnace (Vehlow 2008a)

The process of incineration is in constant development, primarily to maintain and improve its environmental performance and to reduce costs (Vogg and Vehlow 1993).

The energy recovery from a modern waste incineration plant has a high potential (Figure 2.8). Boiler efficiencies of such plants can be higher than 80%, the power efficiency ranges between 20% and 25%; in modern plants with boilers made from high corrosion resistance alloys, power efficiency can reach up to 30% (Vehlow 2008a) The best strategy is usually combined heat and power (CHP). In this type of configuration, overall energy efficiency can reach more than 60%.

Incineration in Latin America

Incineration in Latin America is applied to treat, for the most part, hospital waste, instead of MSW (Acurio et al. 1997, PAHO 2005). To date, the costs of this technology are far too high to be considered by local governments as an appropriate solid waste management technology. Even though, incinerators have been built in several cities in developing countries, they have not worked as expected. The lower heating value is an important parameter describing MSW quality. Usually, the calorific value of the waste in developing countries is low (Figure 2.9) (UNEP 2005, Vehlow 2008b), and hence not able to sustain combustion, thus additional fuel is needed, increasing the operation costs.

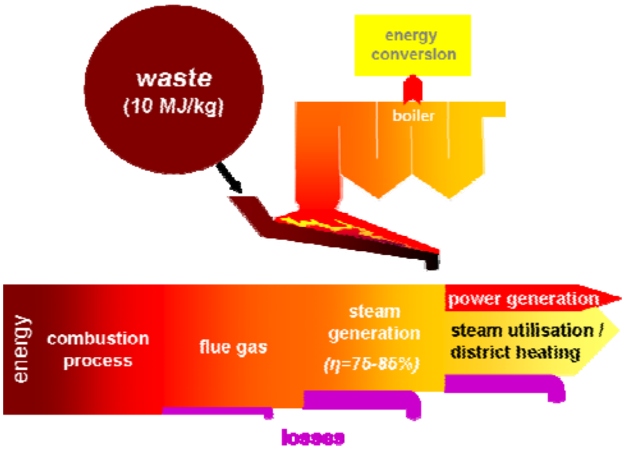


Figure 2.8 Energy flow diagram – Waste incineration facility (Vehlow and Seifert 2003)

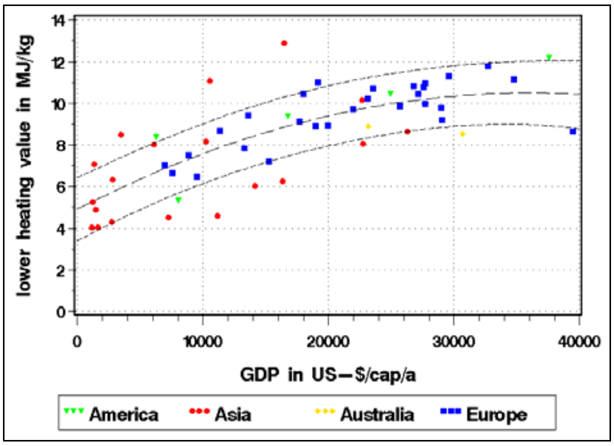


Figure 2.9 Lower heating value of MSW for different regions (Vehlow 2008b)

One municipal incinerator did operate in Mexico City, however, it was closed in 1992. Because of improper operation the incinerator did not meet emission standards (Acurio et al. 1997). MSW incinerators were also tried in São Paulo and Buenos Aires, but they are not operative at the present time, because the operation and maintenance costs were excessively high, along with environmental problems, associated with improper operation (PAHO 2005). In these countries, there was no monitoring activity to prove the efficiency and the incinerator's compliance with the required standards. Additionally, specific technical expertise and related general repair and maintenance technology are often absent in developing and emerging nations.

2.1.7 Transfer

At transfer stations, the waste is transferred from collection trucks to larger transportation units. The use of transfer stations is economically feasible for urban areas which are located far away from waste treatment facilities or from final disposal sites. They become necessary when the specific characteristics of urban settlements do not allow the access of large trucks for direct waste collection, as in the case of several slum areas in developing countries (UNEP 2005). The appropriate implementation of transfer stations reduces air emissions, energy use, truck traffic and road wear and tear (US EPAa).

The majority of the cities in Latin America with a population of more than one million have transfer stations, as well as cities of middle size with important economic activities (PAHO 2005).

2.1.8 Landfilling

The aim of sanitary landfilling is the controlled disposal of solid waste on the land. Modern landfills are well engineered facilities that are located, designed, operated and monitored to ensure environmental and human protection (UNEP 2005). However, in Latin America, practices of disposal vary from dumping of waste on the outskirts of towns or riverbanks to controlled disposal on hydro geological suitable locations (PAHO 2005).

Proper landfilling should not negatively affect the public welfare of current and future generations. Even after closure of landfill sites, waste continues to decompose, increasing levels of leachate and landfill gas, posing a hazard to the environment for several decades. The maintenance phase of a landfill exceeds therefore its operation phase. For this reason, collection and treatment of leachates and landfill gas should take place for several years after closure of the sites. Landfilling presents several problems. The intermediate and final products of the acidic decomposition phase (hydrogen sulphide, mercaptanes, esters, alkyl benzenes), even in very small traces, present strong odors, easily perceivable in air. Additionally, non emplaced waste can also emit strong odors (Clauß 2006). During operation of landfills, dust is dispersed by the wind and moving vehicles, essentially in roads from and to the landfill. The release of landfill emissions has local as well as global ecological consequences. Pollution of water bodies occurs at the local level, but it can last for several centuries. Moreover, landfill gas emissions, with methane as main component, have a strong impact on global climate change. Even though, in normal dilution, the landfill gas is not toxic, if it migrates to close rooms or basements it could displace oxygen, causing suffocation of people. Additionally, because of its methane content, landfill gas is combustible and even explosive under certain conditions. Furthermore, a comparative study between different waste management systems (Bates 2009) including waste to energy plants, MBT and landfill with energy recovery showed that all waste treatment options had a lower environmental impact than landfilling.

Landfills in Latin America

The use of landfills in Latin America and the Caribbean has increased significantly in recent decades (PAHO 2005). Numerous landfills located in capitals and other large cities, however, are more similar to controlled dumps, usually there is a checking, but not weighting of the trucks entering the site. In several cases, waste pickers are working on the facilities, but not sleeping there and often there is a daily cover for the waste. However, there is neither clay nor synthetic lining, and there is lack of leachate collection systems. In most cases, there is not monitoring and treatment of emissions after landfill closure (PAHO 2005).

Some large cities in the region, including Belo Horizonte, Buenos Aires, Guayaquil, Medellin, Mexico City, Santiago de Chile and Sao Paulo, do have state of the art landfills. Landfill design typically consists of an initial clay layer, followed by sand or ground stone layer. Synthetic liners are not usually used, except for some new landfills in Argentina, Brazil and Chile. Leachate collection and treatment systems are usually used. As a rule, the landfills are subdivided into cells, having chimneys for gas ventilation. Waste is covered daily with topsoil. When full, landfills are closed by covering with a clay layer and topsoil.

Meeting all construction requirements in low and middle income countries presents technological and economic constraints (UNEP 2005). Hence, priorities should be focused on the protection of human health and the environment.

2.1.8.1 Landfill post closure

Landfill emissions have to be controlled and treated until their amount reaches environmentally acceptable levels. Several strategies have been developed to reduce the long term impacts of the landfills. In Germany, for instance, it is necessary to install a composite liner, which significantly reduces leachate production. Additionally, landfill gas has to be collected and treated (Heyer et al. 2005). It is argued, that in this strategy the emission potential remains high as a result of the conservation of the waste in the landfill, if the liner collapses the emissions from the landfill will occur at this time. Other strategies suggest to reduce the emission potential before the landfill cover is put in place (Heyer et al. 2005).

A landfill should be released from post closure when the results from control and supervision measures indicate that the landfill does not show adverse environmental effects. The European Union utilizes a time scale of at least 30 years, up to 100 years (Heyer et al. 2005), at the present time it is hard to predict longer post closure measurements.

2.1.8.2 Landfill gas

Landfill gas consists of intermediate catabolic products, produced within the landfill by microbial degradation (Clauß 2006). Landfill gas develops under anaerobic conditions, and typically its composition is about 40% to 64% CH_4; 40% to 50% CO_2, together with small amounts of hydrogen, hydrogen sulphide (H_2S), carbon monoxide (CO), mercaptanes and water vapor. The range of these trace gases is strongly dependent on the composition of the deposited waste.

Landfill gas can be collected by horizontal or vertical pipes (Clauß 2006). The gas collected can be combusted in high temperatures flares, or it can be used to generate heat and electricity or as a source of fuel for vehicles. Figure 2.10 shows a simplified collection system for landfill gas including flaring and gas utilization.

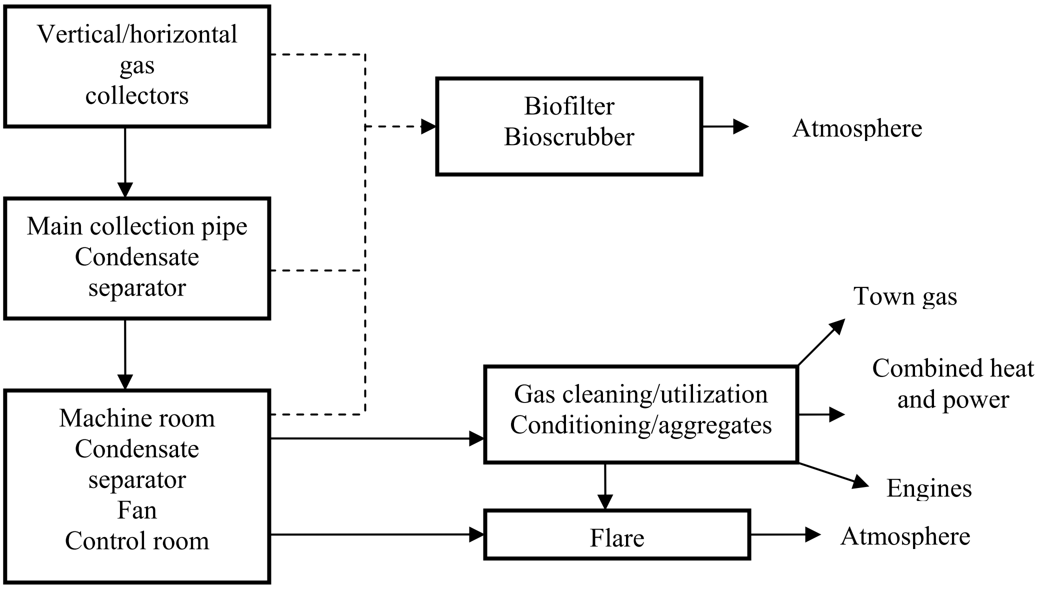


Figure 2.10 Simplified landfill gas collection system (based on Clauß 2006)

Frequently, landfill gas has to be upgraded before use, particularly if it is to be used as a source of fuel for an internal combustion engine, or to be injected into public utility transmission networks.

Use of landfill gas in developing countries

In low and middle income countries, there are rarely laws setting down the degree of biogas collection required in sanitary landfills. Hence, most of the projects for landfill capture, combustion or utilization of landfill gas in these countries are implemented as clean development mechanisms (CDM) of the Kyoto Protocol. Through the CDM, industrialized countries with greenhouse gases (GHG) reduction obligation are able to provide financial support for GHG reduction in developing and emerging countries. The dual goals of the CDM are to promote sustainable development, and at the same time, to allow industrialized countries to earn emissions credits from their investments in emission reducing projects, in developing countries.

In July 2010, there were 117 registered landfill gas CDM projects in the world, 50% in Asia, 45% in America and 5% in Africa. Approximately, half of these projects corresponds to landfill gas capture and flaring and the other half to capture with energy recovery. Apart from China, the majority of the projects are taking place in Latin American countries. Opportunities for landfill gas projects under the Kyoto Protocol exist, and these opportunities are expected to continue beyond the end of the first Kyoto commitment period in 2012.

2.1.8.3 Landfill leachate

Leachate is generated by the passage of water through the solid waste deposited in landfills. The composition of leachates is affected by the type of solid waste deposited, the size and age of the site and the speed and channels of water flowing through the waste. Leachates are formed by organic and inorganic compounds, such as N_2 components, salts and heavy metals. The amount of leachate produced depends on the precipitation, evaporation, surface runoff and outflow close to the surface. These factors depend on the soil character and the vegetation. Vegetation contributes to reduce the amount of precipitation reaching the landfill surface. Further leaching can occur over a longer period even after sealing the surface of the landfill.

There are several leachate treatment methods, adapted from conventional wastewater treatments. Frequently, a pre-treatment takes place to prepare the leachate for further processing. The second stage includes processes designed to remove heavy metals, suspend solids and color. The third stage includes biological processes to remove the organic loading and ammonia (UNEP 2005). The purification of leachates takes place usually in separated leachate treatment plants at the landfill site.

2.2 The Informal Sector in Solid Waste Management

An effective definition of the term informal sector is difficult to find, its real meaning and scope remains controversial. The definitions of the informal sector and the methodologies employed to measure it vary within regions (Forastieri 1999) making difficult to compare and evaluate available data. According to the International Labor Office definition, *"the urban informal sector can be characterized as a range of economic units in the urban areas, which are mainly owned and operated by individuals, either alone or in partnership with members of the same household and which employ one or more employees on a continuous basis in addition to the unpaid family worker and/or casual employees. Typically these units operate on a small-scale, with a low level of organization and little or no division between labor and capital. They are engaged in the production and distribution of goods and services with the main objective of generating employment and basic income to the persons concerned" (ILO 1993).*

The informal sector is a key component of the economy and the labor market in numerous low and middle income countries (Hussmanns 1999). In countries with high rates of population growth and migration to urban areas, as several countries in Latin America, the informal sector tends to absorb most of the growing labor force in urban areas. Informal sector employment is a necessary survival strategy in countries that lack social safety nets, such as unemployment insurance or where earnings, particularly in the public sector, and pensions are low (Hussmanns 1999).

2.2.1 The informal sector in recycling activities

Studies suggest (Medina 2008, Spies and Wehenpohl 2006) that about one percent of the population in developing countries lives from the collection, sorting and recycling of waste materials. As a rule, these people work parallel to the formal solid waste management system. They work on their own, however, and are not contracted by the municipalities or any other entities associated with the waste area. They do not pay tax and are excluded from social welfare and insurance schemes (Wilson et al. 2006). Through its diverse activities the informal sector is of significance for the economic and ecological aspects of solid waste management.

The basic motivation of the informal workers is revenue generation, and the absence of more attractive employment possibilities. Informal waste sector activities related to materials collection, separation and recovery (Medina 2000, Pizarro 2005, Wilson et al. 2006).

In Latin America, there are segregators in practically all large and medium size cities, who work at generation sources, on streets, in collection trucks and on final disposal sites (Medina 2000, PAHO 2005). The attitude of the formal waste management sector towards informal recycling is often negative, regarding it as backward, unhygienic and generally incompatible with modern waste management (Wilson et al. 2006).

2.2.2 Problems associated with the informal waste sector

Most of the urban informal workers live in poor settlements, lacking basic health and welfare services (Forastieri 1999). Informal workers are in daily contact with toxic substances, healthcare waste and fecal matter. They lack protective equipment, medical examination and treatment. Groups working and living in or close to dumping sites are especially exposed. Studies in the field are very limited, however some research has been done, showing that dumpsite scavengers present low life expectancy, high infant mortality rate, and increased occurrence of infectious disease (Medina 2000, Wilson et al. 2006, Scheinberg et al. 2006).

Generally, when waste is sorted by the informal workers what is not worth for recycling is left on the streets, making it more difficult to carry out formal collection and causing a rejection from the community and the authorities. Furthermore, scavengers at landfills or dumping sites disturb the normal operations of these sites. Another problem is that primary waste collectors are frequently dependent on the prices the wholesalers are willing to pay for the materials. Waste pickers tend to occupy the base of the recycling chain. In general, primary collectors have limited capacity for processing and storing materials and are easily exploited (Wilson et al. 2006).

It is important to notice, that the social status of waste workers cannot be understood only in terms of income earnings. Families living by waste picking are not necessarily the poorest groups in a city. Some studies of waste pickers income in Asian cities (Schübeler 1996) implied that they may earn above the average of other manual workers. But waste workers, formal and informal, are usually inhibited by social barriers from translating earnings into improved standards of living.

2.2.3 Integration into the formal sector

Hitherto, there are no proven concepts about how to integrate the informal waste sector into formal systems. However, studies and pilot projects show (Wehenpohl and Kolb 2007, Spies and Wehenpohl 2006) that informal sector involvement in recycling process can help to reduce negative environmental impacts and have overall economic benefits. Moreover, the organization degree of the informal waste collectors, their access to waste, their agreements with other MSW management actors and their political recognition are the main factors for their successful integration.

Over the last years, informal workers in several countries have organized themselves and debated about their right to work in decent conditions within the framework of the public system of waste collection (Waste Pickers without Frontiers). As a consequence, there has been a growing recognition of their activities by local and national organizations. This has led to more supportive public policies and acknowledgment of the important work carried out by the waste pickers, for example in Brazil and Colombia (Waste Pickers without Frontiers).

Traditional social approaches to help waste pickers include (Scheinberg et al. 2006) *welfare based approaches*, which focuses on their daily needs and aim to improve their living conditions; *development orientated approaches* which focuses on social and economic improvements (i.e. education, credit, etc.) to enable pickers to exit their waste occupation; and *right based approaches* which focuses on political, social and institutional aspects of waste picking to strengthen the position of the informal workers and give them a place in society. The condition and position of the waste pickers, both as a poor and as economic actors involved in waste management must be understood in order to apply proper solutions of integration.

It is not an objective of this thesis to focus on the social integration of the waste pickers, but to consider their integration as important actors of the waste management system into the technological schemes.

2.3 Evaluation System for Sustainable Solid Waste Management

Sustainable development is defined in "Our Common Future" Report of the World Commission on Environment and Development as: *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* (WECD 1987).

Solid waste is one of the principal pollution problems in urban areas of low and middle income countries (UNEP 2008). Often, these countries have not the capacity or technical expertise to handle the waste they produce. When this happens, waste enter the ecosystem, contaminating soil, water bodies, the atmosphere, or becoming a source of illnesses, hence, having negative consequences on human health and the environment. Moreover, the costs of restoring the environment and reversing the impacts on health and the environment are very difficult and take several years to complete (UNEP 2008). Against this background, it becomes clear the importance that appropriate waste management has towards the achievement of sustainable development.

The Integrative Helmholtz Sustainability Concept[2] (ISC) (Kopfmüller et al. 2001) serves as theoretical and conceptual tool for the evaluation of MSW management in Santiago de Chile. The concept is based on the three constitutive elements of sustainable development, namely the postulate of inter and intra generational justice, the global perspective, and the anthropocentric view, which are translated into three general goals: to secure human existence, maintain society's productive potential, and preserve society's options for development and action. These goals become operative by a set of sustainability rules, which constitute minimum requirements of sustainability, to which all members of the global society have a right.

This general concept can become more concrete by adaptation to specific application fields. This process has taken place in other studies, in some specific areas, such as mobility, transport, housing and construction, food and land use management (Grunwald et al. 2001). In the solid waste management area, specific sustainability guidelines were defined using the substantial and the instrumental rules of the ISC (Kopfmüller et al. 2005). Moreover, in order to apply the ISC to the specific reality of the Metropolitan Region of Santiago, the conceptual framework was subjected to a process of adaptation (for a detailed description of this procedure see Seidl 2008). In this process, 12 guidelines for a sustainable waste management were developed and several indicators were selected based on an extensive evaluation of the relevant literature about sustainability and waste management for different regions (e.g. Germany, Europe, Latin America). These indicators were assigned to the respective sustainability rules, providing a problem specific indicator system.

The sustainability goal of *maintaining the society's productive potential* (Table 2.4) relates to intergenerational justice, meaning that future generation should have the same possibilities to access different forms of capital (natural, material, human, intellectual and social) as that of

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[2] The Integrative Concept of Sustainable Development was developed within a research project by scientists from the Helmholtz Association of German Research Centres, for detailed information refer to Coenen and Grunwald 2003, Kopfmüller et al. 2001.

present generations. The substitution degree adopted by the ISC accepts to a limited extent the substitution of man made capital for natural capital, in order to preserve the material and immaterial basic functions of nature and the environment. It is necessary to define “critical values” which should not be exceeded for each natural element (Kopfmüller et al. 2001).

Table 2.4 Rules and indicators for a sustainable municipal solid waste management in Santiago de Chile (Seidl 2008)

Objective	Waste management rule	Indicator
Maintaining society’s productive potential	Sparing use of non renewable resources	Quantity of valuable materials recovered from the total waste produced
	Maintaining the regeneration capacity of natural systems	Specific waste generated Greenhouse gas produced during waste management Amount of waste pre – treated before landfilling
	Ensuring safe treatment and disposal	Landfill volume required Landfill capacity
	Ensuring equity in the waste management system	Performance of waste processing plants Recycling services per municipality
Securing human existence	Minimization of adverse health impacts	Exposure of the informal and formal persons employed in the waste management (Noise, odors)
	Ensuring the possibility of independent existence, which fulfills basic needs and creates opportunities for development	Proportion of users of waste disposal facilities Income of the informal sector in relation to minimal wage
	Design of the waste management system at a reasonable overall costs for a fairer development	Fraction of GDP spent on MSW management services Degree of recovery of costs in waste management
Preserving society’s options for development and action	Strengthening of human and knowledge capital	Guarantee of legal access to information for a sustainable waste management
	Ensuring participation and equitable distribution of society groups with influence in the design of the waste management system	Proportion of population participating in waste management decision making processes
	Assumed international responsibility	Direct investments of foreign enterprises in waste management in Santiago
	Strengthening of the guidance and the response of the society to the promotion of decision making in waste management	Presence and enforcement of local regulations supporting recycling and reuse Degree of completion of waste-political objectives
	Encouragement of democracy, transparency, accountability and decision possibilities at the lowest possible level in waste management	Existence of independent, local and regional coordination centers for the regulation of waste disposal

The sustainability goal of *securing human existence* refers to the maintenance of requisites for human livelihood within and between generations.

The last goal, *preserving society’s options for development and action* refers to the access to a long lasting worthy life, for which the individual development options, today and in the future should be kept.

Chapter 3

Research Methodology

In this Chapter, the methodology used to achieve the goals of the research work is presented, including the definition of the study system, which is based on literature review, own data collection and material flow analysis. Additionally, the approach used to assess, under sustainability aspects, the current and future scenarios of MSW management in Santiago de Chile is explained. Likewise, the approach employed to determine alternatives for involvement of the informal waste workers in the formal systems is described. Finally, the methodology used in the development of the future municipal solid waste management scenarios is explained. Besides, the assumptions that were made during the research are presented in this Section.

3.1 Material Flow Analysis

Material flow analysis (MFA) is a scientific method that studies the flow or fluxes of materials, together with their transformation processes through a spatial and temporal defined system. This methodology was chosen, because it offers the possibility of transforming a complex system into a more understandable one, it uses basic material balance calculations and it can be used as a base for decisions in solid waste and resource management. MFA allows to identify and describe the most important good sources, sinks and transfers within a given time period. In the 1970s MFA was used to investigate urban management. Nowadays, the methodology has been applied to several sectors, including waste management (Fehringer et al. 2004).

The MFA, according to (Brunner and Rechberger 2004) relates to the flow analysis of *substances,* which are chemical elements (e.g. oxygen, carbon) or compounds (e.g. methane, carbon dioxide), and *goods* which are substances or a mixture of them (e.g. paper, drinking water, fuel). In MFA, *processes* are defined as the transportation, transformation, storage and changes in the value of materials in a system. The storage of materials in a process is defined as the stock. In sinks (e.g. landfills) goods and substances can be stored for long periods.

3.1.1 System definition

Defining the system in a MFA allows to establish which processes, goods and substances are to be considered within the system. In the present research, the study system corresponds to the municipal solid waste management within the 52 municipalities that form the Metropolitan Region of Santiago (MRS). The temporal boundary selected is one year, being this the time period for which the balance is performed.

The processes to be considered within the research boundaries correspond to the functional elements of solid waste management (Section 2.1) existing in Santiago de Chile:

1. Formal collection and transport of MSW
2. Informal collection and transport of MSW
3. Treatment of MSW, including biological, mechanical or thermal technologies
4. Final disposal of MSW

For the system investigated, MSW, formed by food waste, yard waste, paper and cardboard, plastics, metals, glass and others, is generated outside the system by households and businesses, and imported into the system. These materials suffered transformation inside the system, partly resulting in exported flows, which correspond to secondary raw materials to be used by production companies, and emissions occurring during the different processes (Figure 3.1).

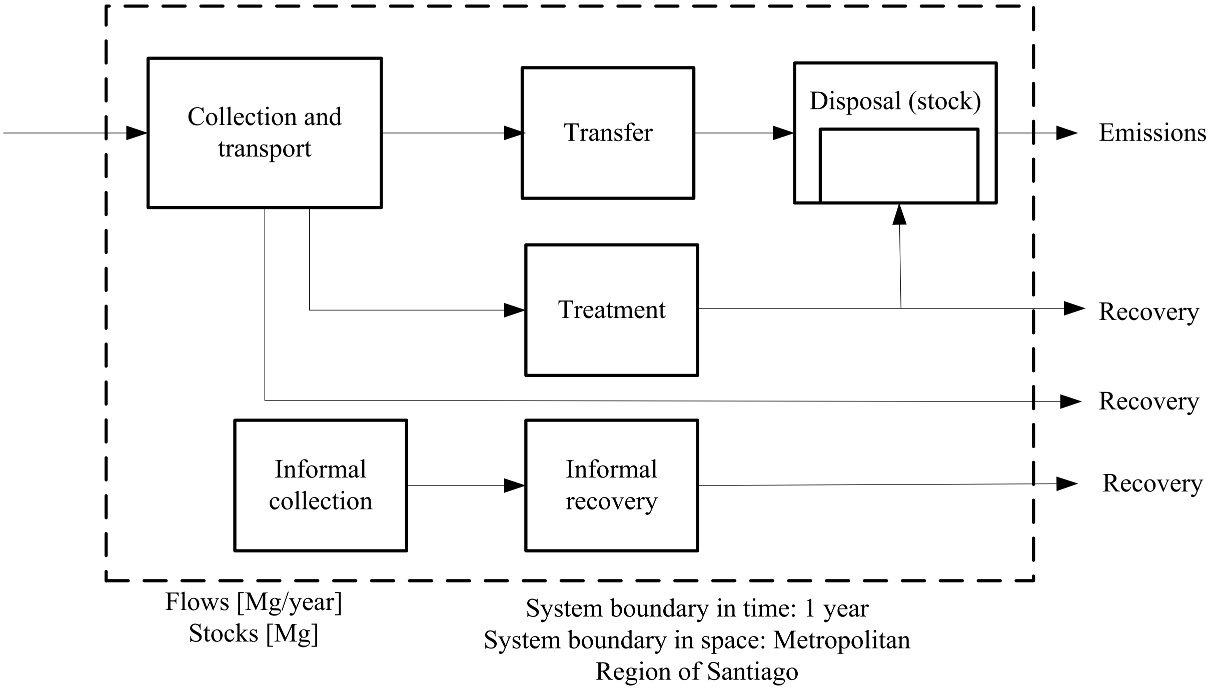

Figure 3.1 General system definition of waste management in Santiago de Chile (derived from Brunner and Rechberger 2004)

3.1.2 Data collection

Data collection involved the literature review of national, regional and municipal publications and records related with municipal solid waste management in Santiago de Chile. Because of scarcity of publications related with recycling and recovery, in particular information about the informal sector, additional field research was carried out in Santiago de Chile during October 2007, May to July 2008 and November 2009. The following approach was followed:

Background research: its aim was the identification of the functional elements existing within the management of MSW in Santiago de Chile, and of the most relevant stakeholders. It included visits to two of the three landfills of the MRS and to the largest material recovery plant of the MRS, located in the municipality of Ñuñoa.

Field research: the aim of this step was to improve the quality of the data gathered during the background research. Qualitative research methods such as semi and unstructured interviews[3], fieldwork and observation were conducted. The analysis of the data was carried out qualitatively and quantitatively.

The first step during the field research was the elaboration of a list of important stakeholders in the waste management field. This list included those municipalities in the MRS with recycling programs. Once these municipalities were identified, following activities were carried out:

a) Semi structured interviews were held with functionaries working at the waste management department of the respective municipality, where drop-off systems and/or segregated collection programs are offered. The objective of these interviews was to understand the operation of the separated collection process, the capacity of associated plants, materials collected, materials' sources and markets.

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[3] Semi structured interviews use a guide, including both closed and opened-ended questions, but in the course of the interview, the interviewer has the chance to adjust the sequence of the questions to be asked and to add questions based on the context of the participants' responses.
In unstructured interviews the researcher comes to the interview without the theoretical background, having conversations with the participants and generate questions in response to the interviewees' narration (Zhang and Wildemuth)

b) Semi structured interviews in public institutions: these interviews were held in the National Commission of Environment[4] (CONAMA) and the Ministerial Health Secretary for the Metropolitan Region (Seremi de Salud). The goal of these interviews was to gain information about quantities of MSW deposited in landfills. In addition to gather information about waste management plans, policies and priorities regarding waste management strategies for the incoming years.

c) Semi structured interviews in organizations were held in “Casa de la Paz” (House of Peace) and AVINA, which are non governmental organizations (NGO) working with the waste pickers. Additional interviews were carried out in the “Deutsche Gesellschaft für Technische Zusammenarbeit” (German Technical Cooperation, GTZ), which is also involved in several projects within waste management and renewable energies in Chile.

d) Semi structured interviews in private production companies were held in companies using secondary raw materials in manufacturing processes (e.g. scrap, paper). The aim of these interviews was to know their linkage with middlemen and waste pickers, and to determine flows of recycled materials.

e) Semi structured interviews in charity institutions were held in institutions having agreements with production companies to promote recycling within a social framework through drop-off schemes. The aim of these interviews was to obtain information about the logistics for the collection of the materials, which are the benefits and costs, who pay them, how is the participation of the householders and their motivation, what expansion plans exist and if there is a competition against the informal sector.

In order to define the main characteristics of the informal sector the following approach was followed:

f) Unstructured interviews were conducted with informal waste collectors during the field visits in residential and commercial areas of Santiago de Chile.

g) Semi structured interviews with leaders of organized groups of collectors and middlemen.

h) Field visits to stock centers, managed by organized groups of primary collectors.

3.1.3 Calculation of material flows

After identification of the most important processes in the system, the next step corresponded to the estimation of flows within and without the system boundaries.

3.1.3.1 MSW flow model

The waste generation of Santiago de Chile was calculated with a linear modeling approach Equation (1):

$$M^* = \sum_{j=1}^{J} m^*_j \qquad \textbf{Equation (1)}$$

Where: M^*: waste mass flow generated

m^*_j: waste mass flow treated or disposed of with method j

The MSW management system of Santiago de Chile was analyzed using the waste flow system defined in Table 3.1 and Figure 3.2.

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[4] Since October 2010, the National Commission of Environment became the Ministry of Environment of Chile

Now, if M^{*}_{mn} is the waste flow from node m to node n (m, n: 1,2,3) the condition in each node can be calculated as follows:

Node 1 $$M^{*}_{C} = M^{*}_{12} + M^{*}_{13} + M^{*}_{14}$$ **Equation (2)**

Node 2 $$M^{*}_{T} = M^{*}_{12}$$ **Equation (3)**

Node 3 $$M^{*}_{RM} = M^{*}_{13} + M^{*}_{23}$$ **Equation (4)**

Node 4 $$M^{*}_{L} = M^{*}_{24} + M^{*}_{14}$$ **Equation (5)**

Where:
M^{*}_{C}: waste mass flow collected by collection method
M^{*}_{T}: waste mass flow sent to treatment
M^{*}_{RM}: waste mass flow sent to production companies for recycling
M^{*}_{L}: waste mass flow finally disposed in landfills

Table 3.1 Nodes of the MSW flow in Santiago de Chile

Node number	Node name	Process
1	Collection	Formal collection mixed waste Formal segregated collection Informal collection Drop-off systems
2	Treatment	Biological treatment Mechanical treatment
3	Recycling	Manufacturing companies
4	Final disposal	Landfills in Santiago de Chile

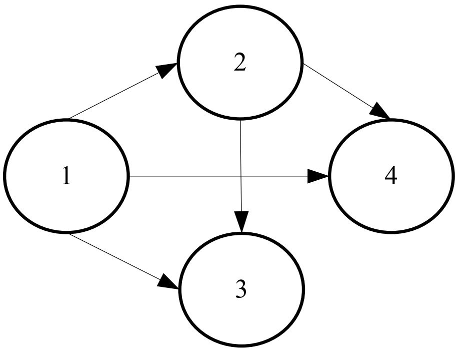

Figure 3.2 Network model of MSW flow system

By using a modification of Equation (1), M^{*}_{mn} can be calculated as follow:

$$M^{*}_{12} = \sum_{j=1}^{J}\sum_{k=1}^{K} m^{*}_{jk}$$ j: collection method
k: treatment method
Equation (6)

$$M^{*}_{13} = \sum_{j=1}^{J}\sum_{k=1}^{K} m^{*}_{jk}$$ j: collection method
k: recycling
Equation (7)

$$M^{*}_{14} = \sum_{j=1}^{J}\sum_{k=1}^{K} m^{*}_{jk}$$ j: collection method
k: final disposal site
Equation (8)

$$M^{*}_{23} = \sum_{j=1}^{J}\sum_{k=1}^{K} m^{*}_{jk}$$ j: treatment method
k: recycling
Equation (9)

$$M^{*}_{24} = \sum_{j=1}^{J}\sum_{k=1}^{K} m^{*}_{jk}$$ j: treatment method
k: final disposal site
Equation (10)

The amount of waste from treatment remaining for disposal and the amount from treatment sent to recycling can be expressed with Equation (11) and Equation (12) respectively.

$$M^*_{24} = TC_k \cdot M^*_{12}$$ **Equation (11)**

$$M^*_{23} = TC_k \cdot M^*_{12}$$ **Equation (12)**

Where: *TC_k*: transfer coefficients for each treatment process k. These transfer coefficients were obtained from field research and literature review.

3.1.3.2 Identification of municipal solid waste flows

As Equation (6) shows, the waste flow M^*_{12} is formed by the waste flows from each collection system to each treatment method. The flow information is summarized in Table 3.2.

Table 3.2 Significant waste flows from collection to treatment

Collection / Treatment	Formal collection mixed waste	Formal segregated collection	Informal collection	Drop-off systems
Biological treatment	-	Field research	-	-
Mechanical treatment	-	Field research	Literature research Field research	-

a) Formal segregated collection to biological treatment: waste flows were obtained during own field research, corresponding to the municipalities of La Pintana and María Pinto (Annex A).

b) Formal segregated collection to mechanical treatment: waste flows were obtained during own field research, corresponding to the municipalities of Ñuñoa and María Pinto (Annex A).

c) Informal collection to mechanical treatment (middlemen): the amount of materials handled by the informal sector was obtained by review of significant documents and interviews (Alaniz et al. 1998, Florisbela 2006, Casa de La Paz 2007a, Casa de la Paz 2007b, personal communications with Exequiel Estay, Juan Aravena, and Álvaro Alaniz). Information used to define the total materials collected by one collector on daily basis is presented in Annex A.

The flows associated with Equation (7) are explained in the following paragraphs:

Table 3.3 Significant waste flows from collection to recycling

Collection / Recycling	Formal collection mixed waste	Formal segregated collection	Informal collection	Drop-off systems
Manufacturing companies	-	Field research	-	Field research Calculations

a) Formal segregated collection to manufacturing companies: waste flows were obtained during field research, corresponding to the municipalities of La Florida and Vitacura (Annex A).

b) Informal collection and delivering to manufacturing companies: this flow was not considered, because it was assumed that waste pickers commercialize recyclable only through middlemen.

c) Drop-off collection and delivering to manufacturing companies: these quantities were estimated with Equation (13), and cross checked with information obtained during interviews and field research.

$$M^{*}_{i\;R-DO} = N_{container} \cdot V_{container,i} \cdot \rho_i \cdot f$$ **Equation (13)**

Where: $M^{*}_{i\;R-DO}$: mass flow of good i collected by drop-off system
$N_{container}$: number of containers for each good i
$V_{container}$: volume of container for each good i (volume of these containers was estimated during field research)
ρ_i: density of each good collected obtained by standard volume to weight conversion factors (US EPAb)
f: collection frequency

The flows associated with Equation (8) are summarized next:

Table 3.4 Significant waste flows from collection to final disposal

Collection Disposal	Formal collection mixed waste	Formal segregated collection	Informal collection	Drop-off systems
Landfills in MRS	Literature research	-	-	-

Collection of mixed waste sent to landfills located in Santiago de Chile: this information is published by the Chilean Health Ministry (see Annex A) (Seremi Salud).

The flows associated with Equation (9) are summarized next:

Table 3.5 Significant waste flows from treatment to recycling

Treatment Recycling	Biological treatment	Mechanical treatment
Manufacturing companies	-	Field research

Waste flow from mechanical treatment to manufacturing companies: these waste flows were obtained during field research, corresponding to the municipalities of Ñuñoa and María Pinto.

The flows associated with Equation (10) are summarized next:

Table 3.6 Significant waste flows from treatment to final disposal

	Biological treatment	Mechanical treatment
Landfills in MRS	Field research	Field research

a) Waste from biological treatment to final disposal sites: these waste flows were obtained during field research, corresponding to the municipalities of La Pintana and María Pinto.

b) Waste flow from mechanical treatment to final disposal sites: these waste flows were obtained during field research, corresponding to the municipalities of Ñuñoa and María Pinto.

Other information needed in order to define the system includes:

- Composition of MSW arriving at landfills: this information was derived from a study made at the transfer station of Quilicura (Oddou 2008), corresponding to the landfill Loma los Colorados (Annex A). The MSW composition was disaggregated by municipalities, whose socio-economic classification is known. This classification is also known for the municipalities depositing waste in other landfills of Santiago de Chile. In order to determine the composition of the waste arriving at those landfills it was assumed that municipalities with similar socio-economic classification would have a similar MSW composition.
- Amount of informal primary collectors in the MRS: this value was estimated with Equation (14) and Equation (15):

$$M^*_{RM} = M^*_{R-SC} + M^*_{R-DO} + M^*_{R-IS} \tag*{\textbf{Equation (14)}}$$

$$M^*_{R-IS} = N_{primary\_collectors} \cdot M_{R-IS-pc} \tag*{\textbf{Equation (15)}}$$

$$M^*_{R-DO} = \sum_{i=1}^{I} M^*_{iR-DO} \tag*{\textbf{Equation (16)}}$$

Where:	M^*_{R-SC}:	mass flow of recyclable materials collected by segregate collection methods
	M^*_{R-DO}:	mass flow of recyclable materials collected by drop-off systems
	M^*_{R-IS}:	mass flow of recyclable materials collected by informal primary collectors
	$N_{primary\_collectors}$:	number of informal waste pickers
	$M_{R-IS-pc}$:	mass flux of recyclables collected by one primary collector in one year

The number of waste pickers obtained was cross checked with information obtained in a report elaborated by the Non Governmental Organization “Ecología y Desarrollo” in 1998, and with interviews with stakeholders in Santiago de Chile (Álvaro Alaniz, Andrés Astorga).

3.2 Assessment of Sustainability

In order to evaluate under sustainability aspects the current situation of MSW management, and of the developed scenarios, a “distance” to target evaluation concept was used. The implemented approach is explained in the following Section.

3.2.1 Distance to target approach

The distance to target approach is used to determine how far a given system is located from achieving sustainable development. The procedure to apply the concept included the following steps:

a) Selection of indicators of sustainability: the selected indicators refer to the objectives of sustainability according to the Integrative Sustainability Concept. Criteria to select the indicators included:
    - Validity: indicators should properly reflect how the sustainability of MSW management is affected by changes in indicator values.
    - Data availability: information should be available in time series if possible, and acquisition of this data should be feasible.
    - Possibilities to define quantitative goals: this allows to evaluate if the targets have been achieved or not.
    - Indicators should be easy to understand, even by people or working groups not associated with the field.

b) Derivation of current values of indicators of sustainability.

c) Selection of target values for selected indicators: after selection of indicators it is necessary to define desired target values. To select these values a hierarchical approach was followed:
    - Consideration of the existing Chilean framework, with respect to already set targets, which might or might not be binding. As a rule, these objectives are proposed by governmental and/or non governmental institutions.
    - For those indicators where there was lack of targets within the Chilean framework, debates with scientists, politicians, public authorities, waste pickers and other stakeholders were carried out. The discussions included desirability of achieving the targets and its feasibility.
    - Finally, literature research about values established and achieved, at the international level were used as references for targets definition.

d) Identification of sustainability deficits: a comparison between the current indicators' values and the desired target values allowed identifying deficits posing a threat to achieve a sustainable system. Those indicators with the greatest distance to target were considered as core risks to the attainment of sustainable development. Moreover, if the negative impacts associated with current indicators' values were a) irreversible, b) showed a particular spatial range, affecting a large number of people and/or c) showed a particular temporal long-term range, indicators were considered to pose a risk against sustainable development.

3.2.2 Derivation of current indicators' values

The selected sustainability indicators are: a) flux of MSW generated, b) amount of mixed waste pretreated to reduce organic carbon content in relation to total mixed waste, c) greenhouse gases emissions from MSW management activities, d) MSW fraction that is recovered as material or energy, e) costs of MSW management in relation to GDP and f) income level of primary collectors in relation to individual household income.

3.2.2.1 Flux of MSW generated

The total quantity of MSW is obtained with Equation (1). The material flux is the quantity of material per capita, considering the population of the MRS.

3.2.2.2 Amount of mixed MSW pretreated to reduce organic carbon content in relation to total mixed waste

This indicator corresponds to the quantity of mixed MSW which undergoes a biological or thermal pretreatment in order to reduce its organic carbon content, before final disposal in landfills, with respect to the total quantity of mixed MSW collected.

3.2.2.3 Greenhouse gas emissions emitted at MSW treatment facilities

Calculations were performed for relevant GHG in MSW management: CO_2, CH_4 and Nitrous Oxide (N_2O). However, CO_2 emissions from biogenic sources were not taken into account, because the materials were originally grown by photosynthesis, thus during natural decay they would have simply closed the loop of the carbon cycle with release of the CO_2 back to the atmosphere (IPCC 2007). The biogenic fraction of MSW is significant, for most countries the figures ranges from 50% to 70% (Vehlow 2008a). In low and middle income countries this is attributed to the large fraction of food waste, whereas in industrialized countries the contribution comes from higher content of paper and cardboard (Vehlow 2008a).

CH_4 emissions from landfills were considered even though the source of the carbon is primarily biogenic, because the CH_4 is created and emitted as a consequence of human activity and the global warming potential of CH_4 is 25 larger than that of CO_2. In the cases when the CH_4 emitted from the landfill was recovered as biogas, and then either flared or combusted in an engine to generate energy, the produced CO_2 was not taken into account, because of its biogenic origin and therefore short-cycle carbon.

Emissions from transport, from operation and from disposal facilities were not taken into account. Emission reductions due to the application of compost instead of nitrogen fertilizers were not taken into account for the current situation, because this practice does not take place at the moment in Santiago de Chile. However, to recognize the potential of avoided GHG emissions as a reason of fertilizer application, an offset of 10% of total CO_2 emissions from composting was assumed in the scenario evaluation. This value has been used in other studies as well (Prognos 2008, Haight 2004).

Calculated emissions were transferred to Global Warming Potential (GWP) units. The GWP conversion factors used are shown in Table 3.7, referred to a 100 year time horizon.

Table 3.7 Global warming potential values (IPCC 2007)

Greenhouse gas	GWP [$CO_{2\text{-eq}}$]
CO_2	1
CH_4	25
N_2O	298

3.2.2.3.1 Emissions from landfill sites

A proven way to predict the gas production of a landfill corresponds to the use of models. A common method used in German speaking countries is the correlation of *Tabasaran and Rettenberger* (Tabasaran O. 1987) which was used in the present research because of its relative simplicity.

This correlation is based on the initial organic content of the MSW, assuming that this organic content will be degraded by anaerobic bacteria producing CO_2 and CH_4. In a simplified way, the anaerobic decomposition can be written as follow, taking glucose as an example (Maurer and Winkler 1982):

$$C_6H_{12}O_6 \longrightarrow 3CO_2 + 3CH_4$$

1 mol C = 12 g C equivalent to 22.4 l gas, thus:
1 g C = 1.868 l gas

The total organic carbon (TOC) can be divided into one part which is dissimilated and one part that is assimilated into microbial cell matter. When increasing temperature, the rate of dissimilation increases faster than the rate of assimilation. Therefore, the ratio between what is dissimilated, i.e. transformed into biogas, and what was available can be approximated by Equation (17), developed by Tabasaran and Rettenberger. This equation was derivated from experimental results.

$$G_e = 1.868 \cdot C_0 \cdot (0.014 \cdot T_L + 0.28) \qquad \textbf{Equation (17)}$$

Where:			
	G_e:	total landfill gas production potential	[Nm^3/Mg_{waste}]
	C_0:	flux of total organic carbon	[kg_{carbon}/Mg_{waste}]
	T_L:	temperature of the landfill body	[°C]

Determination of total organic carbon (C_0)

The carbon content that is of interest in the biogas production is that which is susceptible for biodegradation. According to the literature, for MSW this value ranges between 170 and 220 kg_{carbon}/Mg_{waste} (Kranert et al. 2010). For the specific case of Santiago de Chile, C_0 was derived from the current waste composition, and the carbon content of specific waste fractions found in the literature (Fricke et al. 2002). The waste characteristics used for the model calculations and the results of the TOC for the MSW arriving at the landfills in Santiago de Chile are presented in Annex A.

The derivated value for the current situation was used for the MSW arriving in landfills during the time span 2001 and 2010. To determine C_0 in the scenarios, information about the waste composition (characterization) and the total organic fraction of the individual fractions were used. The composition of the waste arriving at landfills changes in each scenario, because of changes in the quantity of biowaste deposited in the landfills.

The course of gas production per year can be described by a first order reaction:

$$G^*_{s,t} = G_e\left(1 - e^{-kt}\right) \cdot M^*_L$$ **Equation (18)**

$$k = \frac{-Ln(0.5)}{t_{0.5}}$$ **Equation (19)**

Where:	$G^*_{s,t}$:	specific landfill gas production until time t	[Nm³]
	k:	generation rate constant	[year^{-1}]
	M^*_L:	waste flow deposited in landfills in a specific year	[Mg/year]
	t:	deposition time	[year]
	$t_{0.5}$:	half life time	[year]

Calculation of the methane generation rate constant (k)

Because of lack of measurements taken at the landfills in Santiago de Chile, the method of Garg et al. was used (Garg 2006) to estimate the methane generation rate constant (*k*), in Equation (18). Four major parameters are used as input to this model, precipitation, temperature, waste composition and landfill depth. This method allows determining the landfill temperature, using the precipitation average and the environmental temperature of Santiago de Chile, parameters that are known. Table 3.8 shows the values used in the model of Garg for the estimation of *k*.

Table 3.8 Parameters used to determine the generation rate constant (*k*) in the landfills of the MRS (Vogdt 2009, CONAMA 2001b, Oddou 2008)

Parameter		Value
Ambient temperature	[°C]	14.3
Annual precipitation	[mm]	301
Landfill deep	[m]	5
Biodegradable fraction	[%]	54
Landfill temperature (T_L)	[°C]	39
Generation rate constant (k)	[year^{-1}]	0.022

The landfill gas production in a given year can be calculated with the following equation:

$$G^*_t = G_e \cdot \left(k \cdot e^{-kt}\right) \cdot M^*_L$$ **Equation (20)**

Where:	G^*_t:	landfill gas production in a given year t	[Nm³/year]

The GHG emissions for a given year are then calculated with the following equation:

$$Em^L = G^*_t \cdot x^{LG}_{CH4} \cdot F_{v-m} \cdot (1 - \varepsilon^{collection}) \cdot GWP_{CH4} \cdot M^*_L$$ **Equation (21)**

Where:	Em^L:	GHG emissions emitted from landfills
	F_{v-m}:	factor to transform the volume units of methane to mass units (normal conditions)
	x^{LG}_{CH4}:	share of methane in the landfill gas (assumed in 55%)
	$\varepsilon^{collection}$:	collection efficiency of landfill gas. The value used correspond to estimations given at the landfill site during field research, corresponding to 26%
	GWP_{CH4}:	global potential of methane (Table 3.7)

3.2.2.3.2 Emissions from composting plants

During composting with an optimal oxygen supply no CH_4 should be emitted. Nevertheless, it is not possible to have optimal oxygen supply at all areas all over the time, therefore small amounts of CH_4 are emitted during composting. In (Cuhls et al. 2008) data for the emissions from different composting plants were compiled and evaluated. The data used in the present research (Table 3.9) correspond to open windrows, because this is the technology used in Santiago de Chile. The emission factors consider the processes of biowaste pretreatment, intensive biodegradation and maturation process.

Table 3.9 Emission factors anaerobic digestion (Cuhls et al. 2008)

Greenhouse gas	***EF*** **[g_i/Mg_{waste}]**
CH_4	1000
N_2O	110

Direct process emissions from composting were calculated using the following equations:

$$Em^{CP} = Em_P^{CP} - Em_A^{CP}$$ **Equation (22)**

$$Em_{Pi}^{CP} = \left(\sum_{i=i}^{i} EF^{CP}{}_{i} \cdot GWP_i\right) \cdot M^{*B}{}_{CP}$$ **Equation (23)**

$$Em_P^{CP} = \sum_{i=1}^{n} Em_{Pi}^{CP}$$ **Equation (24)**

Where:
Em^{CP}: net GHG emissions released from composting processes
$Em_P{}^{CP}$: GHG emissions produced during composting
$Em_A{}^{CP}$: GHG emissions avoided due to fertilizer substitution. An offset of 10% of total CO_2 emissions from composting was assigned.
$Em^{CP}{}_{Pi}$: GHG emissions of component i produced during composting
$EF^{CP}{}_i$: emissions factor of component i in composting processes
$M^{*B}{}_{CP}$: mass flow of biowaste treated in composting plant

3.2.2.3.3 Emissions from anaerobic digestion (AD) plants

In anaerobic digestion processes the net GHG emissions were calculated with the following equation:

$$Em^{AD} = Em_P^{AD} - Em_A^{AD}$$ **Equation (25)**

Where:
Em^{AD}: net GHG emission in anaerobic digestion processes
$Em_P{}^{AD}$: produced GHG emission in anaerobic digestion processes
$Em_A{}^{AD}$: avoided emissions from electricity generation (substitution of natural gas by biogas)

It is important to notice, that only electricity produced was accounted, because it is usually difficult to find an external customer for heat in developing countries (lack of industries, lack of district heating).

Produced GHG emissions (AD)

There are three main sources of emissions in AD processes:

Unintended leakages taking place during the anaerobic digestion process. The assumed amount was 0.5% of total methane produced.

$$Em_1^{AD} = \left(M_{biogas}^{*CH4} \cdot 0.5\%\right) \cdot GWP_{CH4}$$

Equation (26)

Emissions occurring during the maturation process. Data found in (Cuhls C. et al 2008) for composting maturation was used (Table 3.10) because of lack of information concerning anaerobic processes.

$$Em_{2\ i}^{AD} = \left(\sum\nolimits_{i=i}^{i} EF^{AD}{}_{i} \cdot GWP_i\right) \cdot M^{*AD-M}$$

Equation (27)

CH_4 and N_2O emissions occurring during combustion of biogas. The emission factors used (IPCC 2007) are presented in Table 3.10.

$$Em_{3\ i}^{AD} = \sum_{i=1} \left(EF_i^{biogas} \cdot GWP_i\right) \cdot V_{biogas\cdot} \cdot CV_{biogas}$$

Equation (28)

$$Em_P^{AD} = \sum_{i=1}^{3} Em_i^{AD}$$

Equation (29)

Where:
$Em^{AD}{}_1$: emission of methane released from unintended leakages
$M_{biogas}{}^{*CH4}$: flow of methane in biogas
$Em_2{}^{AD}{}_i$: emission of GHG i released from the maturation stage in AD plants
$EF^{AD}{}_i$: emission factor of GHG i in the maturation stage aerobic decomposition
M^{*AD-M}: mass flow sent to maturation stage
$Em_3{}^{AD}{}_i$: emission of GHG i released by combustion of biogas
EF_i^{biogas}: emission factor of GHG i by combustion of biogas
V_{biogas}: volume of biogas burnt in the combustion engine
CV_{biogas}: calorific value of biogas

Table 3.10 Emission factors - different stages of AD processes (Cuhls C. et al 2008, IPCC 2007)

Stage			CH_4	N_2O
Maturation	EF^{AD}	[g_i/Mg_{waste}]	180	73.3
Biogas combustion	EF^{biogas}	[kg_i/TJ]	-	0.1

Avoided GHG emissions (AD)

Emissions associated with the production of energy through fossil fuels that can potentially be replaced by alternative energy sources were estimated and accounted as *avoided emissions*, in the anaerobic digestion process. For this calculation, it was assumed that the share of the electrical grid of the MRS is equal to the “Central Interconnected System”. This is the system which provides Santiago de Chile of electricity (Table 3.11).

Table 3.11 Electrical grid system, MRS (CDEC-SIC)

Source	Share [%]
Hydropower	54
Coal	9
Natural gas	28
Biomass	2
Diesel oil	7

- A power plant efficiency of 40% was used
- Emission factors used correspond to those reported in the literature (IPCC 2007) and are given in Table 3.12

The avoided emissions of combusting biogas to produce electricity were calculated with the following equation:

$$Em_{A}^{AD} = \frac{M_{AD}^{*B} \cdot \left(h_{biogas} \cdot \varepsilon_{be}\right)}{\varepsilon_{pp}} \cdot \sum_{i=1}^{I} \left(EF^{elec}{}_{i} \cdot GWP\right)_{i}$$ **Equation (30)**

Where: $M^{*B}{}_{AD}$: input flow of biowaste to the anaerobic digestion plant
h_{biogas}: specific enthalpy
ε_{be}: efficiency of energy production by biogas combustion
ε_{pp}: power plant efficiency
$EF^{elec}{}_{i}$: emission factor of GHG i by combustion of fossil fuels

Table 3.12 Emission factors - combustion of fossil fuels (IPCC 2007)

Fuel	EF^{elec} [kg$_i$/TJ]	
	CO_2	N_2O
Coal	94,600	1,5
Natural gas	56,100	0.1
Diesel	74,100	0.6

3.2.2.3.4 Emissions from incineration plants

Net GHG emitted during the incineration process were considered, and calculated with the following equation:

$$Em^{wte} = Em_{P}^{wte} - Em_{A}^{wte}$$ **Equation (31)**

Where: Em^{wte}: net GHG emissions released during incineration processes
$Em_P{}^{wte}$: total GHG emissions produced during incineration processes
$Em_A{}^{wte}$: avoided GHG emissions by energy generation from waste (electricity generation)

Analogous to emissions from anaerobic digestion associated to energy production, only electricity generation was taken into account.

Produced GHG emissions (incineration)

For the calculation of the GHG emitted during incineration of MSW, the non biogenic carbon content of the MSW is significant. To calculate emissions associated with incineration following equations were used:

$$Em_{P}{}^{wte} = Em_{CO2}^{wte} + \sum_{i=1}^{I} Em_{i}^{wte}$$ **Equation (32)**

$$Em_{CO2}^{wte} = FC \cdot M_{wte}^{*} \cdot \alpha \cdot \frac{M_{CO2}}{M_{C}}$$ **Equation (33)**

$$Em_{i}{}^{wte} = EF_{i}^{wte} \cdot GWP_{i} \cdot NCV_{waste} \cdot M_{wte}^{*}$$ **Equation (34)**

Where: $Em^{wte}{}_{P}$: CO_2 emissions produced during incineration
$Em^{wte}{}_{CO2}$: CO_2 emissions released during incineration
$Em_{i}{}^{wte}$: non CO_2 emissions of GHG i released during incineration
FC: fossil carbon content of the waste to incineration plant
$M^{*}{}_{wte}$: flow of waste to incineration plant
α: burn-out rate, it describes the actual carbon conversion during combustion (VDI 3460)

M_{CO2}/M_C: factor carbon to carbon dioxide 1 kmol C of 12 kg is converted into 1 kmol CO_2 of 44 kg in a complete conversion
$EF^{wte}{}_i$: emission factor of GHG i during incineration
NCV_{waste}: net calorific value of the waste for incineration

Table 3.13 Emission factors - combustion of waste (IPCC 2007)

Greenhouse gas	EF^{wte} [kg/TJ]
N_2O	4

It is important to differentiate between the fossil and biogenic carbon content of a fuel, which arises as CO_2 during combustion. This distinction is important in terms of CO_2 emissions, because only the fossil share of CO_2 contributes towards the GHG effect (VDI 3460).

The fossil carbon content of the MSW in Santiago de Chile was determined with information about waste composition obtained by sorting analysis (Oddou 2008), and with the fossil carbon share content of characteristic waste fractions, which were obtained from the literature (Fricke et al. 2002).

Avoided GHG emissions (incineration)

The potential for CO_2 savings by generation of electricity from municipal solid waste can be calculated with varying efficiencies of waste incinerators, as Equation (35) shows:

$$Em_A^{wte} = \frac{M^*_{wte}\cdot\left(h_{waste}\cdot\varepsilon_{wte}\right)}{\varepsilon_{pp}}\cdot\sum_{i=1}^{I}\left(EF^{elec}{}_i\cdot GWP_i\right) \qquad \textbf{Equation (35)}$$

Where: $Em_A{}^{wte}$:avoided emissions resulting from production of electricity by incineration of waste
M^{*wte}: input flow of waste to incineration plant
h_{waste}: specific enthalpy of waste
ε_{wte}: efficiency of waste incinerator

3.2.2.3.5 Emissions from MBT plants

Net GHG emitted during the MBT were calculated with the following equation:

$$Em^{MBT} = Em_P^{MBT} - Em_A^{MBT} \qquad \textbf{Equation (36)}$$

Where: Em^{MBT}: net GHG emissions released during the MBT processes
$Em_P{}^{MBT}$: produced GHG emission during the MBT processes
$Em_A{}^{MBT}$: avoided GHG emissions by co-combusting the alternative fuel produced

Produced GHG emissions (MBT)

There are several sources of GHG emissions at MBT plants, depending on the layout chosen:

$$Em_P{}^{MBT} = Em_{P1}^{MBT} + Em_{P2}^{MBT} + Em_{AD}^{MBT} + Em_L^{MBT} \qquad \textbf{Equation (37)}$$

- Emissions during the mechanical biological treatment itself:

$$Em_{P1}{}^{MBT} = EF^{MBT}\cdot M^{*MBT} \qquad \textbf{Equation (38)}$$

- In MBT biodrying, emissions occurring during co-combustion of the alternative fuel produced, associated with its fossil carbon content were considered:

$$Em_{P2}^{MBT} = FC_{RDF}\cdot M^*_{RDF}\cdot\alpha\cdot\frac{M_{CO2}}{M_C} \qquad \textbf{Equation (39)}$$

- In MBT – AD, emissions occurring during the anaerobic digestion stage were considered (Em_{AD}^{MBT}), and calculated as explained in 3.2.2.3.3
- The remaining waste fraction sent to the landfill also produces GHG emissions (Em_{L}^{MBT}), which were taken into account.

Where: Em_{P1}^{MBT}: GHG emissions released during the MBT process
Em_{P2}^{MBT}: GHG emissions released during the co-combustion of alternative fuel
Em_{AD}^{MBT}: GHG emissions released during the AD process
Em_{L}^{MBT}: GHG emissions from landfilling of the residual waste
EF^{MBT}: Emission factor in MBT processes. Because of lack of information in the IPCC guidelines, the value used was taken from a study elaborated by (Prognos 2008): 27.2 kg CO_{2eq}/Mg_{waste}
M^{*MBT}: flow of waste to MBT plant
FC_{RDF}: fossil carbon content of alternative fuel
M^{*}_{RDF}: flow of alternative fuel to be co-combusted

Avoided emissions (MBT)

Depending on the layout chosen, avoided emissions correspond to:

$$Em_{A}^{MBT} = Em_{A1}^{MBT} + Em_{A2}^{MBT}$$ **Equation (40)**

- Thermal substitution of fossil fuel (black coal and oil diesel), during the production of cement, by co-combusting the alternative fuel produced in the layout biodrying. Avoided emissions can be calculated with following equation:

$$Em_{A1}^{MBT} = \frac{Q_{cc\cdot} \cdot \frac{M_{CO2}}{M_{C}} \cdot \left(\frac{1}{CV_{FF}} - \frac{FC_{RDF}}{CV_{RDF}} \right)}{M^{*}_{RDF-req}}$$ **Equation (41)**

- Substitution of fossil fuel in electricity generation by biogas, in the layout anaerobic digestion is calculated with Equation (30).

Where: E^{MBT}_{A1}: avoided GHG emissions by thermal substitution of fossil fuel in cement plants
Q_{cc}: heat consumption in cement clinker
CV_{FF}: calorific value of fossil fuel being substituted
CV_{RDF}: calorific value of alternative derived fuel
$M^{*}_{RDF-req}$: quantity of refused derived fuel necessary to substitute the heat consumption in the clinker

3.2.2.3.6 Emissions from recycling processes

GHG emissions associated with recycling waste fractions were calculated on the basis of recycled waste flows and GHG emission factors, as shown in the following equation:

$$Em^{RM_j} = M^{*}_{RMj} \cdot EF^{RM}$$ **Equation (42)**

Where: E_m^{RMj}: net GHG emissions released during the recycling of material j
M^{*}_{RMj}: mass flow of material j for recycling
EF^{RM}: net GHG emission factor of recycling material j

Because of lack of other information, emission factors used in the calculations (Table 3.14) were derived from a European level study (Prognos 2008).

Table 3.14 Emission factors - recycling (Prognos 2008)

EF^{RM} [$kgCO_{2eq}$ /Mg_{waste}]	Paper	Glass	Metals (steel)	Aluminum	Plastic
Emissions generated	180	20	22	700	1,023
Avoided emissions	-1,000	-500	-2,047	-11,800	-1,437
Net results	-820	-480	-2,025	-11,100	-414

3.2.2.4 MSW recovered as material or energy

The recovered MSW quantity is defined as materials recovered for recycling and materials recovered for energy:

$$M_R^* = M_{RM}^* + M_{RE}^* \qquad \textbf{Equation (43)}$$

Where: M^*_R: mass flow of MSW recovered
M^*_{RM}: mass flow of MSW recovered for recycling
M^*_{RE}: mass flow of MSW energetically recovered

3.2.2.5 Fraction of GDP spent on MSW management

This indicator was calculated as follow:

$$C^{GDP}{}_{MSW} = \frac{C_{MSW}}{GDP} \cdot 100\% \qquad \textbf{Equation (44)}$$

Where: $C^{GDP}{}_{MSW}$: costs of MSW management expressed as share of the GDP of Santiago de Chile
C_{MSW}: total costs of MSW management
GDP: gross domestic product of Santiago de Chile

For the calculation of this indicator following assumptions were made:

- The current unitary costs of collection, transfer stations and landfills in Santiago de Chile were used.
- For the estimation of the unitary costs of the alternative MSW treatment, the cost functions found in (Le Bozec A. 2004) were used.

Unitary costs used in the calculation are show in Table 3.15.

Table 3.15 Unitary costs of MSW management in the MRS as used in the calculations (Le Bozec A. 2004)

Process	Unitary Cost [US$/$Mg_{waste}$]
Collection	26[a]
Transfer station	7[a]
Landfill	10[a]
Composting	25
Mechanical biological treatment	24
Material recovery facilities	11

a: unitary prices in the MRS in 2007, calculated with information found in (Internet: SINIM)

3.2.2.6 Income level of primary collectors in relation to individual household income

For the estimation of this indicator following assumptions were made:

- Income of informal workers is expressed in terms of the average household income of Santiago de Chile. In 2006 this value was CHP 714,000 (US$ 1370) per household and month, with a household size of 3.7 the value corresponds to US$ 369 per person and month.
- Selling prices of materials used in the calculations are given in Annex A. These prices correspond to market prices in 2009.

3.2.3 Sustainability assessment of current MSW management

The current situation of MSW management in Santiago de Chile was evaluated on the basis of the distance to target approach (Section 3.2.1). The application of this concept allowed identifying the most urgent concerns and priorities for required actions in the field.

3.2.4 Sustainability assessment of the informal waste sector

In order to evaluate how the informal waste sector contributes to sustainable development, two different hypothetical situations were modeled, analyzed and compared. In the first situation, it was explored which were the effects resulting from an *exclusion*[5] of the informal workers from the waste management system (collection, classification and handling recyclable materials); assuming that their daily activities were extremely restricted, and they did not have any access to solid waste sources. On the contrary, in the *inclusion*[6] situation it was investigated which were the effects of a widely acceptance of public authorities and civil society to work together with the informal primary collectors.

These two situations were assessed on the basis of the selected sustainability indicators and on the distance to target approach.

3.3 Analysis of Organization Experiences within the Informal Waste Sector

The objective of this analysis was to determine options to involve the participation of the informal waste workers in the formal MSW system in Santiago de Chile. To achieve this aim, participation and organization experiences of the waste pickers into technical waste management systems, taking place during the last 25 years in Latin America were selected. The main criterion for the selection was the availability of information.

Analysis scheme

The approach used to evaluate the contribution to sustainability of the involvement of informal waste workers into formal systems is based on the model developed by Grafakos et al. (2001). In this model the experiences and how they took place should be analyzed at four levels:

- Policy/regulations: referring to the main policies, regulations and informal rules related to MSW management.
- Organization: it refers to the stakeholders, their relationships and agreements.
- Technological means: it refers to the type, adequacy and availability of the technology used.
- Performance: it relates to the contribution towards sustainability. Within this research, this contribution was evaluated by means of the Integrative Sustainability Concept (Section 2.3.1).

The relationships between these conditions levels are shown in Figure 3.3. For each condition level in the model of Grafakos, indicators were developed in order to measure the contribution of

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[5] Exclusion of waste pickers from the waste management system

[6] Inclusion of waste pickers in several ambits of the waste management system

the experience to sustainability. In the present research, these indicators were adapted to accomplish with the sustainability rules of the Integrative Sustainability Concept.

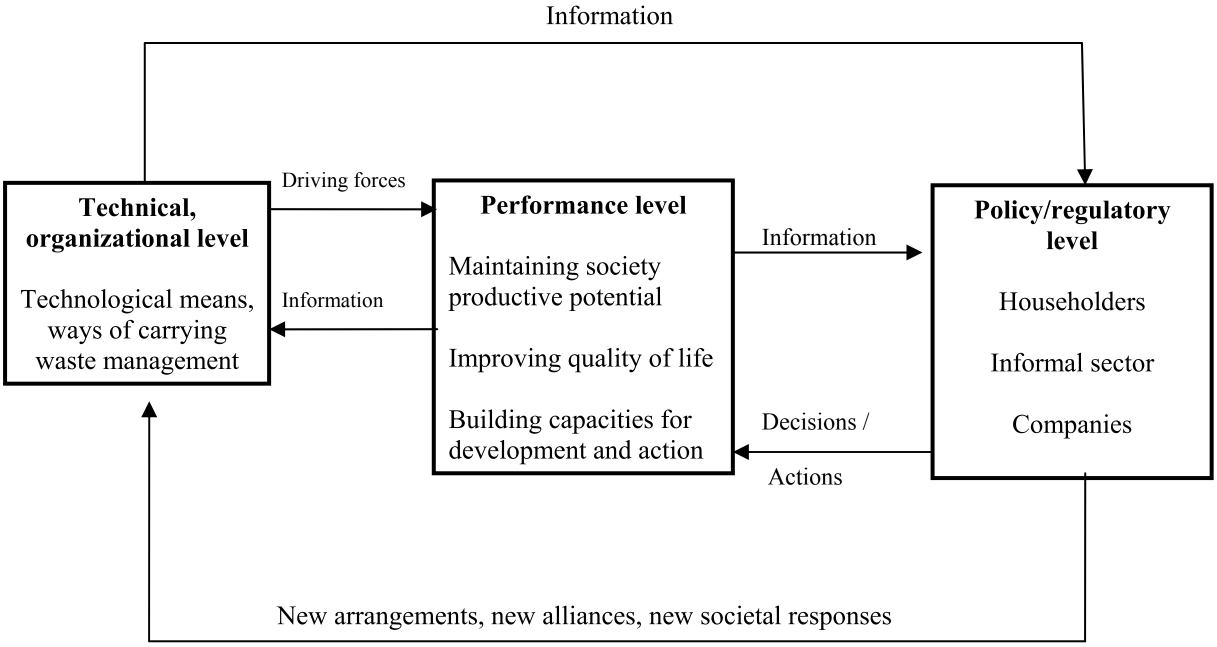

Figure 3.3 Interactions among indicator levels for evaluation of the selected experiences of the informal sector organization (Grafakos et al. 2001)

The outcome of this assessment was used to develop possible integration measures for the informal sector and to improve the sustainability of MSW management in Santiago de Chile.

3.4 Scenarios of MSW Management

Scenarios are a key concept for prospective analysis, describing events and trends as they may evolve. The scenario technique provides a well established tool in order to deal with complexities, interrelations, and dynamics taking place in society. This technique helps to support decision and politic makers to establish strategies for alternative futures (Kosow and Gaßner 2008).

In this research, the explorative framework scenarios developed within the Risk Habitat Megacity (RHM) Project were used. The scenarios explored what is possible regardless of what is desirable. The scenarios developed within the RHM Project were: *Business as Usual (BAU), Collective Responsibility (CR) and Market Individualism (MI)*, for a time horizon from 2010 to 2030. Scenarios with a larger time horizon may loose plausibility, and the farther distant the point in time selected for study lies in the future, the smaller will be the extend of available knowledge of this future (Kosow and Gaßner 2008).

A contextualization of these framework scenarios was developed for the specific case of MSW management in Santiago de Chile, within this research work. The method used for the development of solid waste management scenarios was based on explorative and qualitative and quantitative techniques. Explorative, because the scenarios try to identify possible alternatives rather than desirable or normative futures. Qualitative approaches were used in the development of the storylines[7], and quantitative modeling was used to determine specific variables that define specific characteristics of the MSW management system until the year 2030, to maintain coherence with the framework scenarios of the RHM-Project. The use of

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[7] Storylines are the qualitative and descriptive component of a scenario, they reflect the assumptions about drivers of change and can describe the consequences of a scenario (Rounsevell and Metzger 2010)

the contextualized scenarios, together with the normative targets enabled to visualize, to compare and to assess potential alternative MSW management paths.

Table 3.16 Indicators used in the assessment of selected experiences (derived from Grafakos et al. 2001)

Waste management guideline[8]	Policy/ regulatory	Organizational	Technical	Performance[9]
Sparing use of non renewable resources	Relevant legislation allowing separation or recycling Incentives or barriers for the introduction of recycling practices	Length of trading chains Existence of junk shops, middlemen (existence of a market for recyclables)	Source separation (voluntary / part of MSW management)	Recover ratio of materials
Maintaining the regeneration capacity of natural systems	Relevant legislation to cleaner disposal/ waste minimization	Existence of authorized body for inspection and maintenance of regulations	Whether sanitary disposal methods are used	Waste generation Ratio of waste sent to landfills
Development of human and knowledge capital	Relevant framework for training, division of tasks, responsibilities	Training for waste pickers and/or citizens	Ways of monitoring Supervision waste pickers activities	Quality of the service given by pickers Quality of recyclable materials
Minimization of adverse health impacts	Labor regulations that employees should meet	Training for employees regarding safety Provision of health insurance	Provision and use of protective equipment	Number of accidents, diseases Exposure of workers
Financial viability	Ways of cost recovery (fees, taxes, subsidies)	Access to credit Source of revenue Reliability of suppliers/buyers	Revenue collecting methods	Degree of cost recovery Stability of prices
Guaranty of the possibility of independent existence, which fulfils the basic needs and creates opportunities for development	Support of actors by law	Negotiation capacity Security of employment, way of formalization	Storing capacity Materials processing	Public objections Penalizations / harassing of actors Income level and coverage of basic needs

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[8] These guidelines were selected from Table 2.6 in Chapter 2

[9] Performance compared to Figure 3.3 indicates improvements in the respective level of sustainability

3.4.1 Qualitative development of scenarios

The methodology followed for the development of the contextualized scenarios is described next.

a) Selection of driving factor categories, drivers of change and keywords: based on the main drivers of change defined for the framework scenarios, those having a strong impact on future MSW management were selected. The analysis of the main driving forces helped to identify the main building blocks of the MSW management scenarios. These drivers of change for the framework scenarios are found in the document *driving factor categories – driving factors – keywords* (Annex B).

b) Development of contextualized storylines for MSW management scenarios: taking into consideration the selected drivers of change, and trends of individual keywords for each framework scenario, it was possible to develop the respective storylines. These storylines were presented, and discussed with important stakeholders of the waste management in Santiago de Chile at a workshop own organized and held in November 2009.

3.4.2 Quantitative development of scenarios

Based on qualitative storylines, the quantitative variables were calculated. These variables allowed a more complete definition of the MSW management systems in the year 2030.

3.4.2.1 Waste generation flux: BAU scenario

The gross domestic product has been widely used to describe the economic prosperity of a country (Section 2.1.1), related with the mean living standard of the population and indicating therefore the ability of the population to consume products and goods, hence to produce solid waste.

The MSW generation for the BAU scenario was calculated based on the hypothesis that the economic development of Chile, i.e. the Metropolitan Region of Santiago influences proportionally the MSW generation per capita. Therefore, relating the GDP based on purchasing-power-parity per capita of the MRS, as economic parameter, with the specific amount of waste generated i.e. landfilled.

Waste landfilled

The time series data used in the determination of the correlation are given in Annex C. This data correspond to specific waste landfilled in Santiago de Chile and the GDP of the region in per capita terms between 1995 and 2008. It should be noted, that the quantity of landfilled waste includes not only household residues, but additionally yard and street cleaning residues, which are not dependant on GDP. It was therefore assumed, that the quantity of yard waste remains constant at the value obtained in 2006, corresponding to 350,000 Mg/year (Wens 2008).

The correlation between the MSW flux and GDP obtained, is of the form:

$$'M_{LBAU} = 0.0294 \cdot GDP^{0.3607}$$

Equation (45)

Where: M_{LBAU}: flux of MSW landfilled [kg/(person·day)]
GDP: Gross Domestic Product [in PPP $\$_{2009}$/(person·year)]

Recycling rate

There are several factors affecting recycling rates, and flux of recyclable material including MSW management policies, household income or demographic variables. Figure 3.4 compiles recycling fluxes for countries with different economic development. A clear linear tendency is observed for countries with a GDP of about US$ 30,000 per capita and year. For more economically developed regions the tendency is less clear, showing even some stability at approximately 0.7 kg/(person·day). This stability can be attributed to the different implementation policies and measurements promoting recycling in such countries.

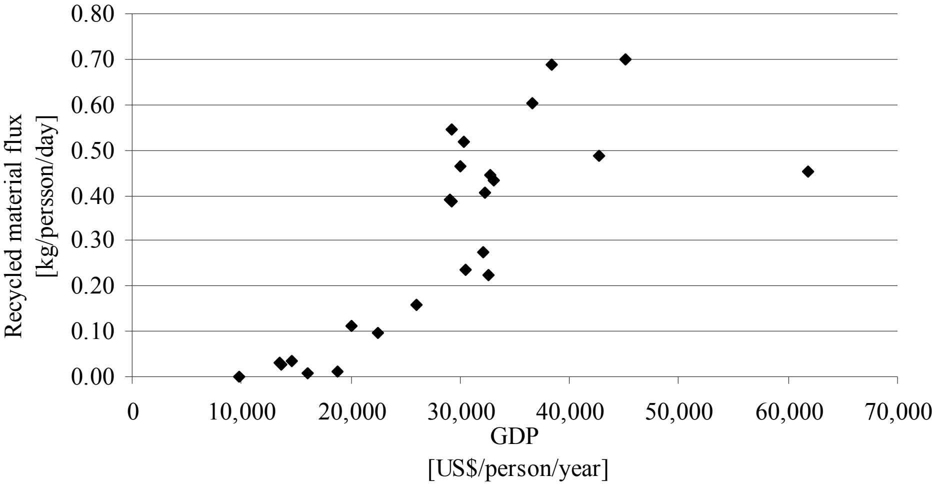

Figure 3.4 Recycling rates in selected countries (OECD 2006-2007, IMF)

It is important to notice that waste statistics vary largely among countries and regions, in some cases this is due to different definitions used, or to waste quantities that are not taken into account, because of unregulated disposal, or illegal burning. The aim of the data shown in Figure 3.4 is only to serve as basis for the correlation developed for waste recycling flux and GDP in Santiago de Chile.

Based on Figure 3.4, it is therefore plausible to assume a linear relationship between the amount of waste recycled and the GDP of MRS. The input data used to estimate the correlation is given in Annex C.

The correlation obtained between the recovered waste flux and the GDP in Santiago de Chile is of the form:

$$M_{R-BAU} = 2.6473 \cdot 10^{-5} \cdot GDP - 0.1908$$

Equation (46)

Where: $M_{R\text{-}BAU}$: flux of MSW recovered [kg/(person·day)]

Waste generation

The approach used in this research considers that the total municipal solid waste production is a function of waste landfilled and waste recovered, as shown in the next equation:

$$M_{BAU} = M_{LBAU} + M_{R-BAU}$$

Equation (47)

Where: M_{BAU}: flux of MSW in the BAU scenario [kg/(person·day)]

The baseline calculation only takes into account the effect of economic development; on the contrary it does not include the influences of other factors, such as urbanization changes, household size, or environmental awareness, in the specific waste generation.

3.4.2.2 Waste generation in alternative scenarios (CR, MI)

A literature research allowed identifying other variables, besides GDP that have an effect on the quantity of MSW generated. The identified variables were: urbanization processes, household size, household income and years of schooling. To calculate the quantitative variables in the alternative scenarios, the development of these parameters were taken into consideration using the following equation:

$$M_i = M_{GDP,i} \cdot (a_i \cdot b_i \cdot c_i \cdot d_i) \qquad \textbf{Equation (48)}$$

Where:
M_i: flux of MSW in scenario i [kg/(person·day)]
$M_{GDP,\,i}$: flux of MSW in scenario i calculated as a function of GDP in scenario i
a_i: parameter considering the change of urban population between scenario i and BAU
b_i: parameter considering the change of household size between scenario i and BAU
c_i: parameter considering the change of household income between scenario i and BAU
d_i: parameter considering the change of years of schooling between scenario i and BAU

The modeling of the scenarios was based on the quantitative trends that are characteristic for the Collective Responsibility and for the Market Individualism scenarios (these trends are found in Annex B). Additionally, it is important to notice that M_{GDP} to be used in Equation (48), is calculated as follows:

$$M_{GDP,i} = 0.0294 \cdot GDP_i^{0.367} + 2.6473 \cdot 10^{-5} \cdot GDP_i - 0.190 \qquad \textbf{Equation (49)}$$

Where GDP is the gross domestic product in the scenario i (Collective Responsibility or Market Individualism)

The development of the other variables taken into consideration in the Collective Responsibility and in the Market Individualism scenarios changes with respect to the BAU scenario, thus the flux of MSW generated in the alternative scenarios differs from that of the BAU scenario no only as a function of the GDP variation.

It is important to notice, that the influence of these variables on the development of MSW differs, therefore the model parameters are quantified through correction factors. Furthermore, the quantification of one type of effect is *ceteris paribus* of effects in other areas. The selected factors are described as:

- Urbanization processes: in several studies (Cailas et al. 1993, Henricks 1994, Hocket 1994) a positive correlation between the urbanization degree and waste generation was found, those more densely populated urban areas produced relatively more waste and it was found that MSW in cities can be twice as large as in rural areas. Urbanization factors also affect indirectly waste generation by changing private consumption. On the other hand, there were a few studies that did not find any correlation. It is thus assumed, that a change of 100% in the urban population of the alternative scenarios, with respect to the BAU scenario, would produce a change of 30% in the specific waste generation of that scenario.
- Household size: It has been found, that household size is a key determinant in overall waste production (Cailas et al. 1993, Dennison G.J., et al. 1996, Jenkins 1993, Beigl et al. 2004, Hockett et al. 1995, Ojeda et al. 2008). Household with larger densities produce less waste per capita than smaller ones. It is assumed that a change of 100% in the household size of the alternative scenarios, with respect to the BAU scenario, would produce a change of -60% in the specific waste generation of that scenario.
- Household income: The generation of MSW can be explained by income spent on private consumption, it has been found that more affluent households are more likely to produce larger quantities of waste, than the less affluent (Dennison et al. 1996, Chang et al. 1993, Dayal al et al. 1993, Cailas et al. 1993, Henricks 1994, Hocket 1994, Ojeda et al. 2008, Orccosupa 2002). It was also found that income and MSW are linked to some extend, at

certain level of income they become de-linked. The turning point occurs at very high levels of value added per capita. It is assumed that a change of 100% in the household income of the alternative scenarios, with respect to the BAU scenario, would produce a change of 80% in the specific waste generation of that scenario.

- Years of schooling: it has been found (Ojeda et al. 2008) that households with only primary education produced more waste than those belonging to professional level. However, not a lot of research has been conducted in this area. For this reason it was assumed that a change of 100% in the years of schooling of the alternative scenarios, with respect to the BAU scenario, would only produce a change of -20% in the specific waste generation of that scenario.

For the calculation of parameters a_i to d_i, (named as g_i) a linear correlation was used:

$$g_i = 100\% + \Delta g_{Bau-i} \cdot CF_g \qquad \textbf{Equation (50)}$$

Where:
g_i: parameters *a* to *d*, for scenario i
Δg_{Bau-i}: variation between BAU scenario and scenario i, for parameter g
CF_g: correction factor for parameters g

Table 3.17 summarizes the results of Equation (50) for each parameter *a* to *d*. The changes between the alternative scenario i and the BAU scenario were provided by the scenario group of the Risk Habitat Megacity Project and can be found in Annex B.

Table 3.17 Correction factors as used in the determination of waste generation for alternative scenarios

	Correction factor CF [%]	Δg Collective Responsibility [%]	Δg Market Individualism [%]	g Collective Responsibility [%]	g Market Individualism [%]
Urban population change	+30	-8.2	2.5	97.5	100.7
Household size	-60	6.7	-6.7	96.0	104 .0
Household income 2030)	+80	-2.4	-3.6	98.1	97.1
Years of schooling	-20	3.4	-3.4	99.3	100.7

For a better understanding, the calculation of the MSW flux for the CR scenario is shown. Equation (49) is substituted in Equation (48):

$$M_{CR} = \left(0.0294 \cdot GDP_{CR}^{0.367} + 2.6473 \cdot 10^{-5} \cdot GDP_{CR}\right) \cdot (a_i \cdot b_i \cdot c_i \cdot d_i)$$

Factors given in Table 3.17 are used in Equation (50), and are substituted in the equation above:

$$M_{CR} = \left(0.0294 \cdot GDP_{CR}^{0.367} + 2.6473 \cdot 10^{-5} \cdot GDP_{CR}\right) \cdot (0.975 \cdot 0.96 \cdot 0.981 \cdot 0.993)$$

Recovering rate

The recycling flows in the Collective Responsibility and Market Individualism scenarios were derived based on the respective storylines, which define the waste management for each scenario. The total recovered flow is given by:

$$M^*_{R,i} = M^*_{R-SC,i} + M^*_{R-DO,i} + M^*_{R-IS,i} + M^*_{R-wte,i} \qquad \textbf{Equation (51)}$$

Where:
M^*_{RE}: recovered flow in scenario i
M^*_{R-SC}: recovered flow by segregated collection method in scenario i
M^*_{R-DO}: recovered flow by drop-off systems in scenario i
M^*_{R-IS}: recovered flow by informal waste pickers in scenario i

$M^{*}_{R\text{-}wte}$: flow to energy recovery in scenario i

3.4.2.3 Waste composition

Figure 3.5 (above) shows that some correlation exists between the GDP of a region and the share of organic waste (food waste). In contrast, if the specific quantity of organic waste per capita is depicted as a function of the GDP (Figure 3.5 below) there is no an obvious tendency. Only 15% of the data shown in Figure 3.5 has an organic generation above 0.6 kg/(person·day). Additionally, 60% of those countries with a GDP lower than US$ 30,000 per capita and year present an organic generation below 0.44 kg/(person·day).

The average amount of biowaste in Santiago de Chile in the year 2007 was 0.43 kg/(person·day). For the calculation of the composition of the MSW in the future scenarios, it was assumed that the organic fraction reaches a maximum of 0.44 kg/(person·day) in 2030.

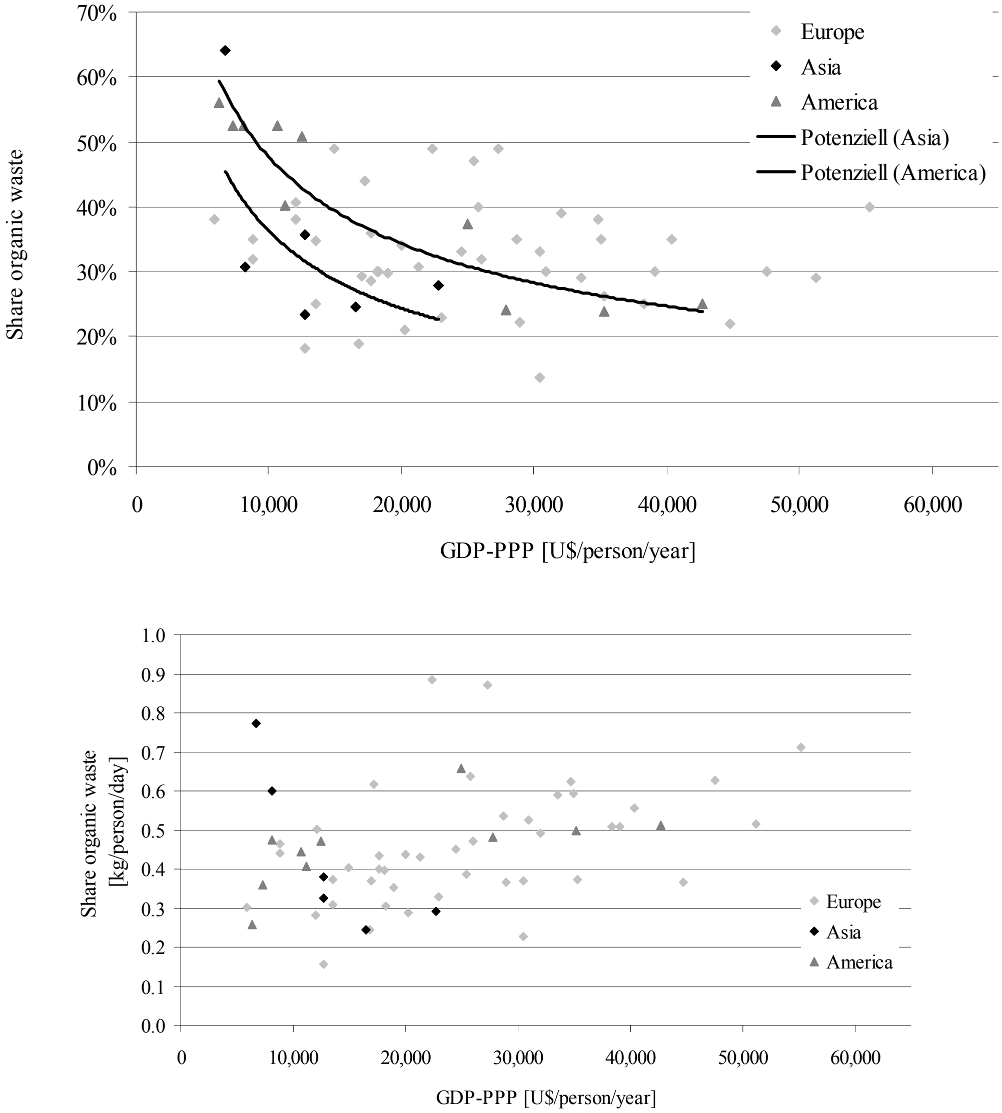

Figure 3.5 Biowaste as a function of GDP in different regions (OECD 2006-2007, IMF 2010, Vehlow 2010)

In order to calculate the composition of the other waste fractions, it was assumed that the relative percentage of paper, cardboard, plastic, metals and glass remains constant within this fraction. The total non-food and yard waste fraction is then calculated with a mass balance:

$$M^{*}_{np} = M^{*}_{i} - M^{*}_{B}$$ **Equation (52)**

Where: M^{*}_{np}: flux of non- food and yard materials in the MSW
M^{*}_{B}: flux of biowaste in MSW

3.4.3 Selection of MSW treatment technologies

Based on the storylines and specific scenarios' characteristics it was possible to develop a general waste mass flow defining the different waste treatments to apply in each scenario. For each of these treatments different technologies exist. The specific choice of which technology to apply is scenario dependent.

The compared technologies included:
Biological treatment
- Composting
- Anaerobic digestion

Energy recovery
- Incineration plant exporting electricity
- Mechanical biological treatment plant where metals are separated and the remaining waste is:
  - Sorted into an biogenic component which is anaerobically digested, and a fraction which is sent to landfills
  - Biodried to produce a refused derived fuel (RDF) which is co-combusted in cement kilns
  - Sorted into an organic component which is anaerobically digested and a fraction which is used to produce a RDF which is co-combusted in cement kilns

Characteristics of a modern plant were used to describe each technology. Each technology was evaluated and compared by means of chosen indicators which are shown in the following section.
Technical aspects
- Quantity of residual waste sent to landfill after treatment
- Quantity of compost produced
- Quantity of metals recovered
- Quantity of energy recovered

Environmental aspects
- Net greenhouse gases emitted related to the facility

Economic aspects
- Capital costs
- Gross production costs
- Revenues

Based on storylines and framework scenario conditions, the weight given to each aspect varies, as shown in Table 3.18.

Table 3.18 Weight assigned to decision-aspects used in the technology selection

	Economic	Technical	Environmental
BAU	3	2	1
CR	2	1	3
MI	3	2	1

Selection matrixes were used to select on one side biological treatment technologies, and on the other, waste to energy technologies.

3.4.3.1 Assessment of technologies

3.4.3.1.1 Composting

The purpose of the plant is to treat the segregated biowaste in order to obtain mature compost. This is achieved by means of a pretreatment step to remove impurities and to prepare the material for the composting process. This process starts with an intensive biodegradation of the waste, which takes place in windrows. The turning of the windrows ensures a good aeration and homogenization of the waste and later on, of the compost. To assure the quality of the compost, a post-treatment procedure is required. The obtained compost is screened for final removal of impurities.

Following data were used in the determination of the mass balance:

- Amount of structural materials (yard waste): 30% required in order to obtain an optimal composition of the waste entering the composting plant (Vogt et al. 2002)
- Impurities in waste input: <5%
- Composition of impurities: assumed to be equal to that of residual waste in the respective scenario
- Efficiency of metal recovery: ranges between 88-98% for ferrous metals (Loll 2002). A value of 93% was used.
- Efficiency of impurities removal at the end: 80% (Loll 2002)

Mass Balance

The following equation was used to calculate the quantity of compost obtained at the end of the composting process:

$$M^{*}{}_{CP-E} = \frac{M^{*}{}_{CP} \cdot (1 - w_{CB}) \cdot (1 - BM \cdot D)}{(1 - w_{CE})}$$

Equation (53)

Where:

$M^{*}{}_{CP-E}$: flow of compost at the end of the composting process
$M^{*}{}_{CP}$: flow to composting process
w_{CB}: water content of $M^{*}{}_{C}$
w_{CE}: water content at the end of the composting process
BM: biodegradable organic matter (volatile solids)
D: degradation degree

Table 3.19 Waste characteristics in composting processes (Kranert et al. 2010)

Parameter		Range	Average
w_{CB}	[%]	50 – 75	65
BM	[%]	35 – 80	65
w_{CE}	[%]	30 – 45	35
Organic substance at the end	[%]	25 – 45	35
D	[%]	30 – 70	50

3.4.3.1.2 Anaerobic digestion

The aim of this plant is to treat the segregated biowaste and to produce biogas. The technology selected was a thermophilic dry, one stage process, which is the most common process for biowaste digestion in Germany (Fricke et al. 2002, Vogt et al. 2002). The separate collected biowaste undergoes a pretreatment step to remove impurities. The anaerobic digestion process takes place in the digester, where biogas, wastewater and a digestion residue are produced. The biogas is combusted in an engine to produce electricity and heat. The digestion residues are further treated in aerobic windrows to produce compost.

Following data were used for the determination of the mass and energy balances:

- Amount of structural materials (yard waste): 20% required in order to obtain an optimal composition of the waste entering the fermentation plant (Vogt et al. 2002)
- Impurities in waste input: <5%
- Composition of impurities: assumed equal to that of residual waste in the respective scenario
- Efficiency of metal recovery: ranges between 88 - 98% for ferrous metals (Loll 2002). A value of 93% was used.
- Efficiency of sieve drum: ranges between 90 - 95% (Loll 2002). A value of 95% was used.
- Composting losses in the maturation step: 16% (Loll 2002)

Biogas produced in the anaerobic digestion facility is collected, treated and burnt to produce energy. The energy obtained was calculated with the following equation:

$$Q^*_{P-B} = V_{biogas} \cdot x_{CH4} \cdot CV_{CH4} \cdot \varepsilon_e \cdot M^{*AD}$$

Equation (54)

Where:		
	Q^*_{P-B}:	flow of energy generated from biowaste
	V_{biogas}:	volume of biogas produced
	x_{CH4}:	volume percentage of methane in biogas
	CV_{CH4}:	calorific value of methane
	ε_e:	energy (thermal or electrical) generation efficiency
	M^{*AD}:	flow to anaerobic digestion process

Table 3.20 Technical parameters for anaerobic digestion processes – one stage (Loll 2002, Vogt et al. 2002)

Parameter		Range	Typical values
Biogas yield	[%]	10 – 16	
V_{biogas}	[m^3_{biogas}/kg_{ODM}]	0.38 – 0.51	0.38
x_{CH4}	[%]	50 – 65	58

Table 3.21 Energy parameters for anaerobic digestion processes – one stage (Loll 2002, Vogt et al. 2002)

Parameter		Range	Average
Energy consumption (total)	[%]	20 – 30	25
Electricity generation	[%]		30
Electricity consumption	[%]		11
Heat generation	[%]		60
Heat consumption	[%]		11
Energy losses	[%]	8 – 12	10

3.4.3.1.3 Incineration

The incineration technology selected was a grate firing system with energy recovery, which represents the best available technology for MSW incineration. The bottom ash can be used after pretreatment in the construction industry. Energy from waste is recovered as electricity. Flue gas cleaning consists of an electrostatic precipitator where dust and flue ashes are separated. Furthermore a spray-dryer, a fabric filter an acid scrubber for hydrogen chloride reduction, a gas desulphurization plant and a selective catalytic reduction for nitrogen oxides reduction are installed. Table 3.22 shows data used in the determination of the mass and energy balances.

Table 3.22 Parameters in waste incineration (Gerlagh 2009, Seifert and Vehlow 2010)

Parameter		Range	Typical values
Metal recovery	[%]		80 ferrous metals 30 non ferrous metals
Fly ash sent to landfills	[%]	1.5 – 2.5	2
Flue gas treatment residues sent to landfills	[%]	1.0 – 2.5	2
Slag to be used in the recycling sector	[%]	15 – 25	16
Electricity generation efficiency	[%]		23

3.4.3.1.4 Mechanical biological treatment - biodrying

The aim of this plant is to produce a high calorific material suitable for combustion. Initially materials are screened, separated and metals are recovered. The low calorific fraction is aerobically stabilized and sent to the landfill. The high caloric fraction is effectively dried and stabilized through a composting process, to produce an alternative fuel which is co-combusted in cement kilns. Following data were used in the determination of the mass and energy balances:

- Efficiency of metal recovery: 82% of ferrous metals, 86% of non ferrous metals (Gerlagh no dated).
- For the production of the alternative fuel a sieving process takes place. Efficiencies of sieving of the waste without shredding are presented in Table 3.23. The values indicate the proportion of materials in a coarse fraction after separation with sieves of 40 mm, 80 mm and 100 mm.
- The high calorific fraction, sent to the production of alternative fuels corresponds to the grain size fraction > 80 mm.
- The alternative fuel produced is used as a combustible in cement kilns, substituting black coal, which is the fuel used currently in the cement plants of Santiago de Chile.
- Total decomposition rate at the stabilization process: 65% (compared Table 3.19).

Table 3.23 Grain size of residual waste (Loll 2002)

		>100	> 80 mm	>40mm
Organic	[%]	15	20	30
Paper/Cardboard	[%]	55	60-70	80
Foils	[%]		85	60
Other plastics	[%]		86	90
Metals	[%]	20	60	80
Glass	[%]		60	80
Diapers	[%]	10	87	100
Textiles	[%]		90	100

3.4.3.1.5 Mechanical biological treatment – anaerobic digestion

In the anaerobic mechanical biological process, analogous to the biodrying plant, the waste input is screened to remove impurities and to recover metals. The high caloric fraction is sent to the landfill. The low caloric fraction is sent to the anaerobic digestion process, where the organic mater is anaerobically decomposed, producing biogas. After the anaerobic digestion process, the digestate is aerobically stabilized. The biogas is combusted in an engine to produce electricity and heat. Following data were used in the determination of the mass and energy balances:

- Anaerobic technology: one stage thermophilic process.

- The mechanical pretreatment of the input is analogous to the pretreatment of the biodrying process. The input to the biological phase is the fraction with grain size < 80 mm.
- Properties of biogas are the same as in the anaerobic digestion process (Table 3.20).
- Efficiency of electricity production and internal consumption are the same as in the anaerobic digestion process (Table 3.21).
- Total decomposition rate at the stabilization process: 20% (Soyez et al. 2000).

3.4.3.1.6 Mechanical biological treatment – biodrying and anaerobic digestion

This facility is the combination of the two previous ones. In a first step the waste input to the plant is screened and separated, to remove impurities and to recover metals. The high calorific fraction is effectively dried and stabilized through an aerobic process, to produce RDF which is co-combusted in cement kilns. The light fraction is sent to the anaerobic digestion process, to be biologically degraded, producing biogas. The biogas is combusted in an engine to produce electricity and heat. After the anaerobic digestion process, the digestate is aerobically stabilized. The production of the high caloric product flow was modeled like the process described in Section 0. and the anaerobic process was modeled as described in Section 3.4.3.1.5.

3.4.3.2 Environmental aspects

GHG emissions associated to composting and anaerobic digestion were estimated as explained in Section 3.2.2.3.

3.4.3.3 Economic aspects

For the calculation of economic aspects, costs' functions found in (Le Bozec 2004) were used. *Capital costs:* The method used for the calculation of capital costs takes into account the capital costs in process or in equipments installed, as well as for civil engineering, building and road systems and the indirect costs such as environmental studies. For the calculation of the *capital costs* following equations were used:

Composting $$C_{cCP} = \left(83.125 \cdot D_{nCP} + 479{,}928\right)$$ **Equation (55)**

Anaerobic digestion $$C_{cAD} = 1{,}000{,}000 \cdot Ln(D_{nAD}) - 2{,}000{,}000$$ **Equation (56)**

Incineration $$C_{cI} = 275.8 \cdot D_{nI} + 18{,}231{,}500$$ **Equation (57)**

MBT biodrying $$C_{cMBT} = 1{,}500 \cdot D_{nMBT}{}^{0.8}$$ **Equation (58)**

MBT AD $$C_{cMBT-AD} = 2{,}500 \cdot D_{nMBT}{}^{0.8}$$ **Equation (59)**

Where:
C_{cCP}: capital costs of composting plant [Euro]
D_{nCP}: design capacity of the composting plant [Mg/year]
C_{cAD}: capital costs of anaerobic digestion plant [Euro]
D_{nAD}: design capacity of anaerobic digestion plant [Mg/year]
C_{cI}: capital costs of incineration plant [Euro]
D_{nI}: design capacity of incineration plant [Mg/year]
C_{cMBT}: capital costs of MBT – biodrying plant [Euro]
D_{nMBT}: design capacity of the MBT-biodrying plant [Mg/year]
$C_{cMBT\text{-}AD}$: capital costs of MBT – anaerobic digestion plant [Euro]
D_{nMBT}: design capacity of the MBT plant [Mg/year]

Operation costs: The operation costs consider the direct costs (labor, energy) maintenance and indirect costs, necessary for the operation of the waste treatment installation. For the calculation of the *operation costs* following equations were used:

Composting

$$C_{ocP} = \theta \cdot \left(0.00031 \cdot w_{tech} + 4.2 \cdot e_{elec} + 3.675 \cdot e_f\right) \cdot M_{biowaste} + 0.047 \cdot \left(83.125 \cdot D_{nCP} + 479{,}928\right)$$

Equation (60)

Anaerobic digestion

$$C_{oAD} = \theta \cdot \left(4{,}256.4 \cdot M_{biowaste}{}^{0.5213}\right)$$

Equation (61)

Incineration

$$C_{oI} = C_F + 1.5 \cdot C_{\mathrm{Re}a} + e_{elec} + C_M + C_R$$

Equation (62)

$$F_c = 366{,}500 + 8{,}365 \cdot D_{nI}$$

Equation (63)

MBT – biodrying*

$$C_{oMBT} = 4{,}000 \cdot D_{nMBT}{}^{-0.4} \cdot M_{MBT}$$

Equation (64)

* source: Tsilemou and Panagiotakopoulos 2006

Where:
C_{oCP}: operation costs of composting plant [Euro]
C_{oAD}: operation costs of anaerobic digestion plant [Euro]
C_{oI}: operation costs of incineration plant [Euro]
C_{oMBT}: operation costs of MBT-biodrying plant [Euro]
w_{tech}: annual average wages for a technical employee. In Chile (IASA 2009) this value is 600,000 Chilean pesos per month, corresponding to 9,583 Euro/month [Euro/month]
e_{elec}: kWh price. In Santiago the electricity price is: 85 Chilean pesos per kWh, therefore: 0.11 Euro/kWh (IASA 2009) [Euro/kWh]
e_f: liter price for fuel. In Chile is: 550 Chilean pesos per liter, therefore: 0.73 Euro per liter (IASA 2009). [Euro/l]
$M_{biowaste}$: annual quantity of treated waste [Mg/year]
M_{MBT}: annual quantity of waste to MBT plant [Mg/year]
θ: overhead and benefits

Estimation of general expenses and benefits: This value varies according to the management of the installation adopted by the local authority:

a) The local authority invests the necessary capital for the construction and operation of the plant. In this case the overheads and benefits are equal to zero (θ = 1). This was the value used in the Collective Responsibility scenario.
b) The local authority pays capital costs and gives the operation to a private company. In this case a fraction of θ is retained and applied to the operation costs (θ = 1.20). This was the value used in the BAU scenario.

C_F: fixed costs
C_R: reagent costs
C_M: maintenance costs
C_R: replacement costs

Gross production costs: The estimation of the annual capital and operating costs makes it possible to evaluate the expenditure in terms of annual plants throughput. The gross production costs do not take into account revenues obtained by sale of compost, or electricity, and were calculated with the following equation:

$$C_{pi} = C_{oi} + \frac{1}{d} C_{ci}$$ **Equation (65)**

Where: $\frac{1}{d} C_{ci}$ depreciation

C_{pi}: production costs of waste treatment i

d: average installation lifetime

3.4.4 Sustainability analysis of scenarios

The most pressing sustainability problems were identified, through the distance to target approach by comparing the values of the targets with the estimated value of the indicators for each scenario.

Chapter 4

Municipal Solid Waste Management in the Metropolitan Region of Santiago

This Chapter provides an overview of the general characteristics of Chile, in particular of the Metropolitan Region of Santiago (MRS), where the capital city of the country is located. This Chapter focuses in the description of the municipal solid waste management in MRS. Special attention is given to existent recycling systems, including publicly organized and informal schemes. Supplementary information about the informal waste sector is provided in Chapter 6. The results provide in this Section were obtained from literature, municipal documents, interviews, own field research and own calculations.

4.1 Chile and the Metropolitan Region of Santiago

Chile is a long, narrow country, located in South America, stretching over approximately 4,329 km from the north to the Magallanes Straits, and 468 km at its widest point near the Magallanes Straits from *Punta Dungenes* to *Islotes Evangelistas* (UC undated). Chile limits with Peru to the north, Bolivia to the northeast, Argentina to the east and the Drake Passage to the south. Chile has an area of 756,102 km² (CIA undated) and an estimated population (2010) of 17,094,270 inhabitants (INEa). The urban population of the country is about 88%. This large urban rate is common in most Latin America countries.

Chile is divided into 15 regions. Every region is further divided into provinces and finally each province is divided into municipalities. Each region is designated by a name and a Roman numeral (Figure 4.1, Table 4.1).

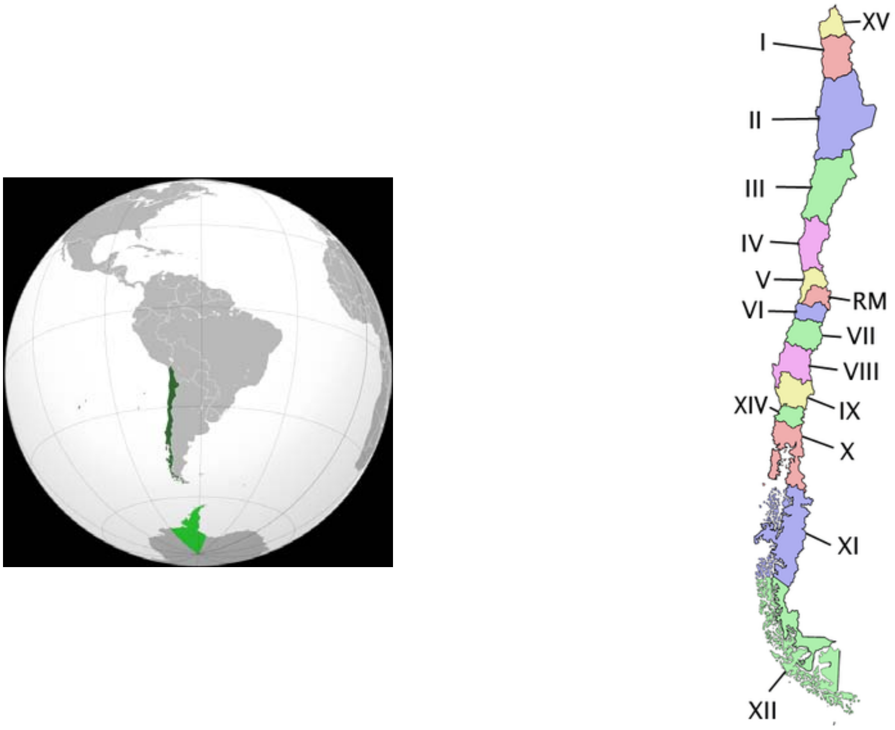

Figure 4.1 Chile and its Regions (CIA undated, Encyclopaedia Britannica 2001)

Table 4.1 Chile Regions

Number	Region name	Number	Region name
I	Tarapacá	IX	Araucanía
II	Antofagasta	X	Los Lagos
III	Atacama	XI	Aisén
IV	Coquimbo	XII	Magallanes
V	Valparaíso	XIII	Región Metropolitana de Santiago
VI	O'Higgins	XIV	Los Ríos
VII	Maule	XV	Arica and Parinacota
VIII	Biobio		

Chile has rapidly grown, in economic terms, since the end of the dictatorship in 1990. In the year 2010, its GDP was US$ 11,428 person (IMF undated) with a national growth of 4.7%.

The Chilean economy is market oriented, characterized by a high level of foreign trade, strong financial institutions and sound policy. Main exported goods include copper, fish, agricultural and forestry products. In December 2009, the Organisation for Economic Co-operation and Development (OECD) invited Chile to become a full member, after a two year period of compliance with organization mandates (CIA undated). The unemployment rate in 2009 was 8.5% (INEb) and the human development index[10] was 0.878, being ranked as the country 44th, and first of Latin America (UNDP 2009).

The MRS is one of the administrative divisions of the country, formed by six provinces and 52 municipalities (Figure 4.4). Santiago de Chile has a mild Mediterranean climate, relative hot dry summers, with more humid and cold winters. The altitude is about 520 m above sea level.

The MRS contains the nation's capital, Santiago de Chile. It limits to the north and west, with the Valparaiso Region; to the south with the O'Higgins Region and to the east with Argentina. It has an area of 15,554 km² (641 km² for the urban area), which represents only 2.05% of the total country's area, but in contrast, according to the most recent Chilean Cense (2002) 40% of the total population of the country lives here (6,066,009 inhabitants) (INEc).

This large urbanization rate has raised environmental problems, one of which corresponds to large quantities of MSW generated and its associated impacts. In the MRS, there is a need to develop adequate and sustainable solutions to manage the total amount of solid waste produced, appropriately.

4.2 Legal Framework of the Municipal Solid Waste Management in the Metropolitan Region of Santiago

Before 1990, the total quantity of MSW generated in Santiago de Chile was deposited of in dumping sites. In 1994, the Framework Environmental Law ("Ley de Bases del Medio Ambiente") was approved, establishing the use of controlled landfills for the disposal of MSW. In the year 1997, the regulations for the Environmental Impact Assessment System (SEIA) entered

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[10] The Human Development Index is a composite statistic used to rank countries by level of "human development", classifying the countries in high developed, developing (middle development), and underdeveloped (low development). The statistic is composed from data on life expectancy, education and per-capita GDP.

into force, requiring an environmental assessment for MSW management facilities. Consequently, nowadays, the waste formally collected in the region is deposited in controlled landfills.

4.2.1 Governance

One particular characteristic of the management of MSW in Chile is the lack of one institution having the total responsibility for the residues' management. For example, each municipality is responsible for the collection, transport and final disposal of MSW. On the other hand, the Health Ministry (Seremi Salud) has, among other responsibilities, some influence in the waste management field, inspecting and supervising the operation of MSW treatment and disposal facilities. The Health Ministry dictates additionally, the guidelines to foresee and prevent occupational and public health risks. Another institution with responsibilities in the waste management is the National Commission of Environment of Chile (CONAMA for its Spanish abbreviation), which is in charge of establishing environmental targets and enforcing their implementation. CONAMA is responsible for the imposition of penalties if environmental regulations are not followed. Finally, the Regional Government of Santiago (GORE Metropolitano) is a coordinator and mediator between these institutions and it is in charge of developing management and residues policies in the region (CONAMA 2005b). Furthermore, even though the municipalities of the MRS are in charge of the collection and disposal of the solid waste, in the majority of the communities these services are carried out by private companies.

4.2.2 Legal framework

The treatment of MSW is ruled by a heterogenic group of laws, decrees and rules:

- Sanitary Code 1968: it establishes the responsibility of the municipalities to collect, to transport and to eliminate waste residues produced on urban ways, appropriately.
- Constitutional Organic Law of Municipalities, within the Constitution of Chile (1980): it establishes, in its article number 19, the right of the inhabitants to live in a pollution-free environment.
- Municipal Revenue Law: it has a general definition of domiciliary solid waste, in its article number six.

As a consequence of the problems faced by Chile in terms of solid waste, in the year 2005 the Integrated Waste Management Policy was approved (CONAMA 2005b). This policy represents an advance in the MSW management of Chile. Its objective is to avoid risk to the environment and public health, related with solid waste management activities. It establishes seven specific objectives, such as the minimization of health impacts caused by improper waste management, improve environmental education and citizens' participation in recycling programs, develop solid waste data bases, among others. The politic includes as well ten guiding principles, based in an integrated waste management system. The policy proposes a hierarchy strategy consisting of the avoidance of waste in first place, followed by recycling strategies and finally, the disposal of waste that cannot be recovered, within an economic fairness framework.

4.3 Municipal Solid Waste Characteristics

As observed in Figure 4.2, the rising in the GDP of Chile (i.e. MRS) has been accompanied by an increase in the MSW generation flux. According to official statistics of the CONAMA, the total MSW generated in the region was roughly 2.9 million tons for the year 2007, corresponding to about 1.2 kg/(person·day). It should be noted, that this value is more similar to waste production in industrialized countries (Vehlow 2008b), which have a higher GDP than Chile. For example, the specific MSW production of Berlin came to 1.4 kg/(person·day) for the year 2007 (BSGUV 2009). This fact might be an indicator of high consumption patterns of the population in the MRS, together with lack of policies and instruments aiming to waste prevention.

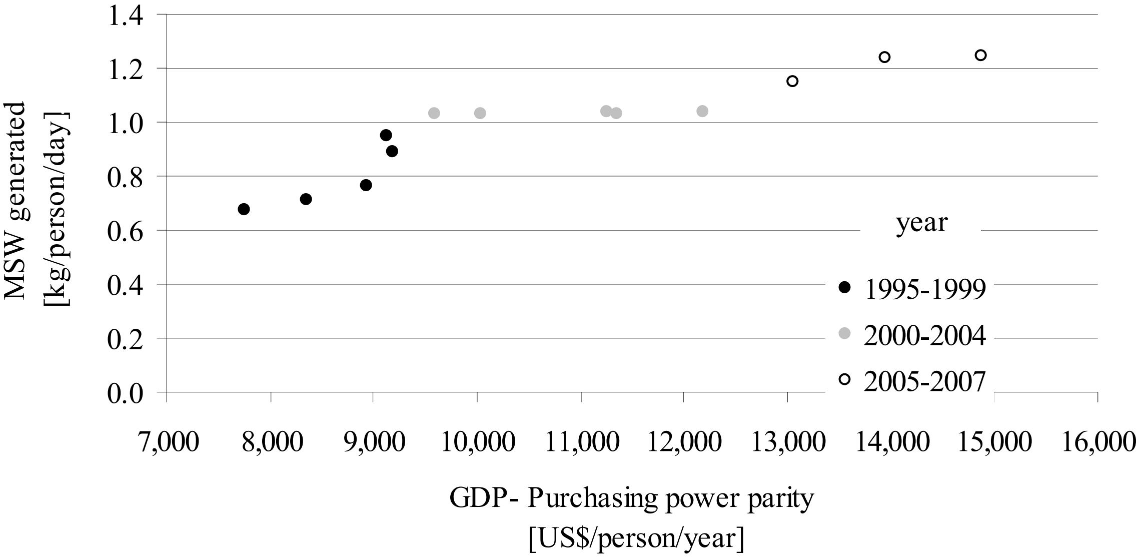


Figure 4.2 Evolution of the municipal solid waste generation in the Metropolitan Region of Santiago (based on: Szantó 2006, IMF undated)

The rapid economic growth of Chile over the last ten years brought about several benefits for most of its inhabitants, including a rise in income levels across all population groups. These rising income levels correlate with variations in consumption patterns, which in turn influence the composition of MSW. The most noticeable changes occurred in the organic fraction (food waste), which declined from 68% in 1990 to 50% in 2007 (Szantó 2006). Hence, the share of other fractions increased, e.g., paper and cardboard from 15% to 18% and plastics from 6% to 10%.

On the basis of a sorting analysis carried out at the transfer station of “Quilicura” (Oddou 2008) and using published data of heating values of single waste fractions (Loll 2002), the approximate net calorific value (NCV) of the MSW arriving at the landfills was calculated. The average NCV obtained is 8,500 kJ/kg_{MSW}. Respective data are presented in Annex A.

Figure 4.3 shows the MSW mass flow in the Metropolitan Region of Santiago. As mentioned above, the annual waste generation amounted to almost three million tons in 2007. About 99% of the mixed MSW is left in bags or containers on the streets (flow 1), where the major part is collected by the publicly organized system (flow 2) and transported to transfer stations and sanitary landfills (flow 3, flow 4). Landfills are the most important functional element of the MSW management in Santiago de Chile; over 86% of the total MSW generated in 2007 was disposed of in sanitary landfills. Approximately 13% of the MSW was collected by the informal primary collectors (flow 5), transported to their houses or stock centers (flow 6) to be further classified by middlemen who are in charge of delivering these materials to paper (flow 7), scrap (flow 8) or plastic (flow 9) production companies. Publicly organized recycling is almost negligible, this includes 0.1% for the segregated collection and separation of inorganic materials (flow 10 to flow 12), and 0.4% for the segregate collection and processing of biowaste (flow 17 to flow 19) with production of compost (flow 21) and 0.7% for collection with drop-off systems (flow 22, flow 24, flow 26). The recycled materials collected by formal systems are also delivered to production companies (flows 13 to flow 16, and flow 23, flow 25 and flow 27). The total recycling rate in 2007 was almost 14%. The respective mass flows for each waste fraction are show in Table 4.2.

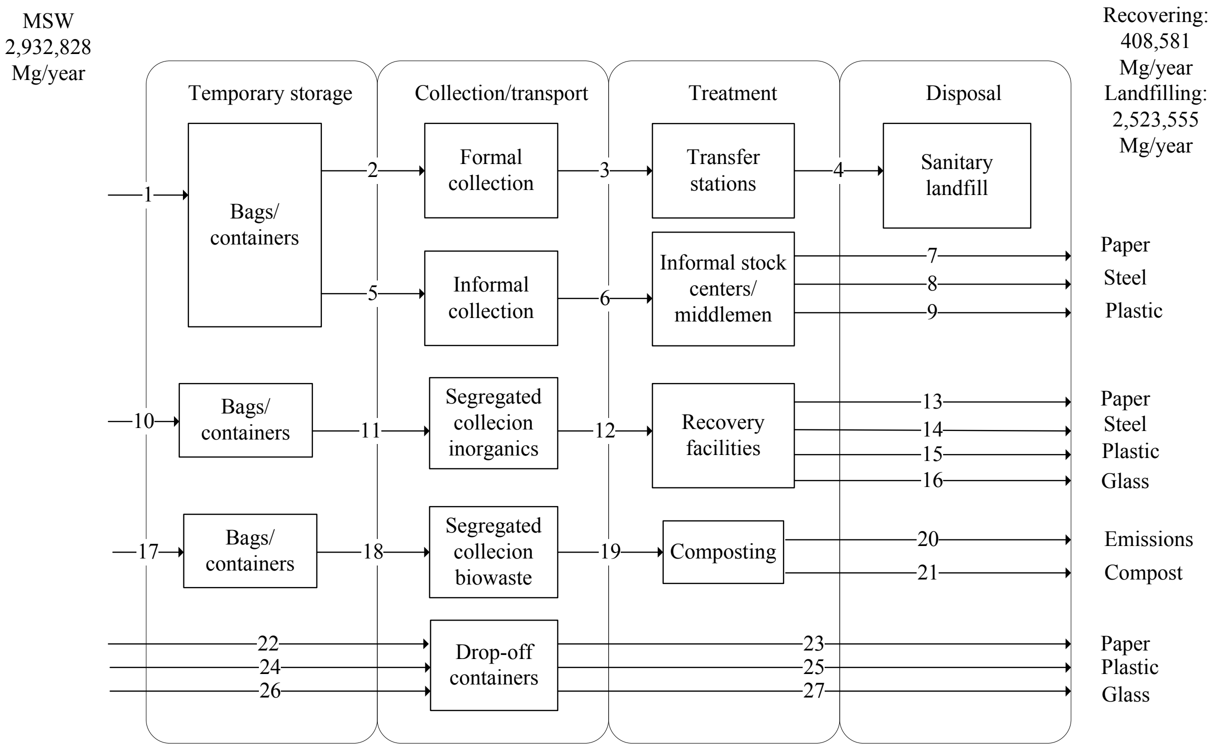


Figure 4.3 Simplified MSW diagram flow in the MRS – 2007

Table 4.2 MSW mass flows – 2007 [thousand Mg/year]

Flow	Total	Biowaste	Paper Cardboard	Plastic	Glass	Metals	Other	Input	Output
1	2,898	1,397	590	273	80	186	372	2,898	
2	2,524	1,397	388	258	80	28	372		
3	2,524	1,397	388	258	80	28	372		
4	2,524	1,397	388	258	80	28	372		
5	374		202	15		157			
6	374		202	15		157			
7	202		202						202
8	157					157			157
9	15			15					15
10	3.8		1.5	0.4	0.9	0.3	0.7	3.8	
11	3.8		1.5	0.4	0.9	0.3	0.7		
12	3.8		1.5	0.4	0.9	0.3	0.7		
13	1.5		1.5						1.5
14	0.3					0.3			0.3
15	0.4			0.4					0.4
16	0.9				0.9				0.9
17	10	9.5					0.5	10	
18	10	9.5					0.5		
19	10	9.5					0.5		
20	7						7		7
21	3	3							3
22	7		7					7	
23	7		7						7
24	0.3			0.3				0.3	
25	0.3			0.3					0.3
26	14				14			14	
27	14				14				14
Total								2,933	408

4.4 Functional Elements of MSW management in Santiago de Chile

4.4.1 Collection

MSW collection services cover the whole MRS, and almost 100% of the inhabitants are served by regular waste collection, with a varying frequency from three times a week to daily (Szantó 2006), particularly in commercial areas and downtown. In the MRS, the sweeping, collection and MSW disposal services are performed by private companies in most of the municipalities, by bidding. These biddings establish private companies' obligations and they are usually of five to six years of duration. In the MRS, collection services are performed by 18 different enterprises; however two of them own 42% of the market. Therefore, there is hardly any competition. 86% of the municipalities of the MRS had a collection contract with a private company in 2008 (Godoy and Ossadón 2009). As a consequence of the different kind of contracts, there are large variations in the collection costs among municipalities. For example, in 2008 the lowest collection cost of US$ 10 per ton of MSW corresponded to the municipality of Pedro Aguirre Cerda, whose average monthly household income was US$ 1,100 (Mideplan 2007). In contrast, MSW management costs in the municipality of Vitacura, amounted to US$ 59 per ton of MSW in the same year. Vitacura is one of the most expensive and fashionable municipalities of Santiago de Chile, with an average monthly household income of US$ 6,500 (Mideplan 2007).

4.4.2 Final disposal of MSW

There are three relatively new sanitary landfills operating in the MRS, one began operations in 1996, the other two in 2002. These landfills are properly authorized by government agencies and technically equipped with bottom liners and collection systems for leachates. The landfills are operated by private companies. Additionally, there is one controlled dumping site ("vertedero de Popeta") still in operation. The dumping site is located in the municipality of Melipilla, and it receives the MSW generated in this community, which correspond to 100 Mg/day, according to official sources the dumping site is to be closed soon (Natalia Garay, GORE).

Figure 4.4 shows the location of the landfills and their respective transfer stations. Additional description of the sanitary landfills operating in Santiago is given in the next paragraphs.

4.4.2.1 Loma los Colorados landfill

Loma los Colorados (Figure 4.5) is operated by the "URBASER-KIASA" Group, a company owned by the Spanish URBASER and by Chilean-American capitals, belonging to Kenbourbe Environmental Engineering KIASA (KDM). The landfill is both the largest and the oldest of the three landfills in operation and it is situated in the municipality of Til Til, 60 km north of Santiago de Chile downtown. It began to receive waste from the transfer station in Quilicura (also own by KDM) in 1996, initially by truck and since 2003, by train, in both cases using silos with external compaction. Although the current contract ends in 2011, it will be renewed automatically for sixteen years if none of the parties cancel the contract earlier. The current landfill input rate is approximately $1.5 \cdot 10^6$ Mg/year, which accounts for 48% of total MSW deposited in the landfills of the MRS. According to the declaration of environmental impact, the landfill is anticipated to reach capacity around 2045.

Regarding technical aspects, this landfill is equipped with geosynthetic materials. Additionally, leachate is collected and sent to accumulation pools and afterwards to a percolate liquids treatment plant, to remove biological, physical and chemical pollutants. Landfill gas is collected and flared since 1998 (CDM 2006a). A landfill gas power plant began operating in November 2009. The plant has two generators of one megawatt power capacity each. The electricity is sold to the national network. The landfill gas that is not used is still being flared, but it is planned to extend the generation capacity to 14 MW by the end of

2011. Moreover, it is planned to extend the total capacity gradually, to generate 28 MW by 2024 (Keller 2010, KDM undated).

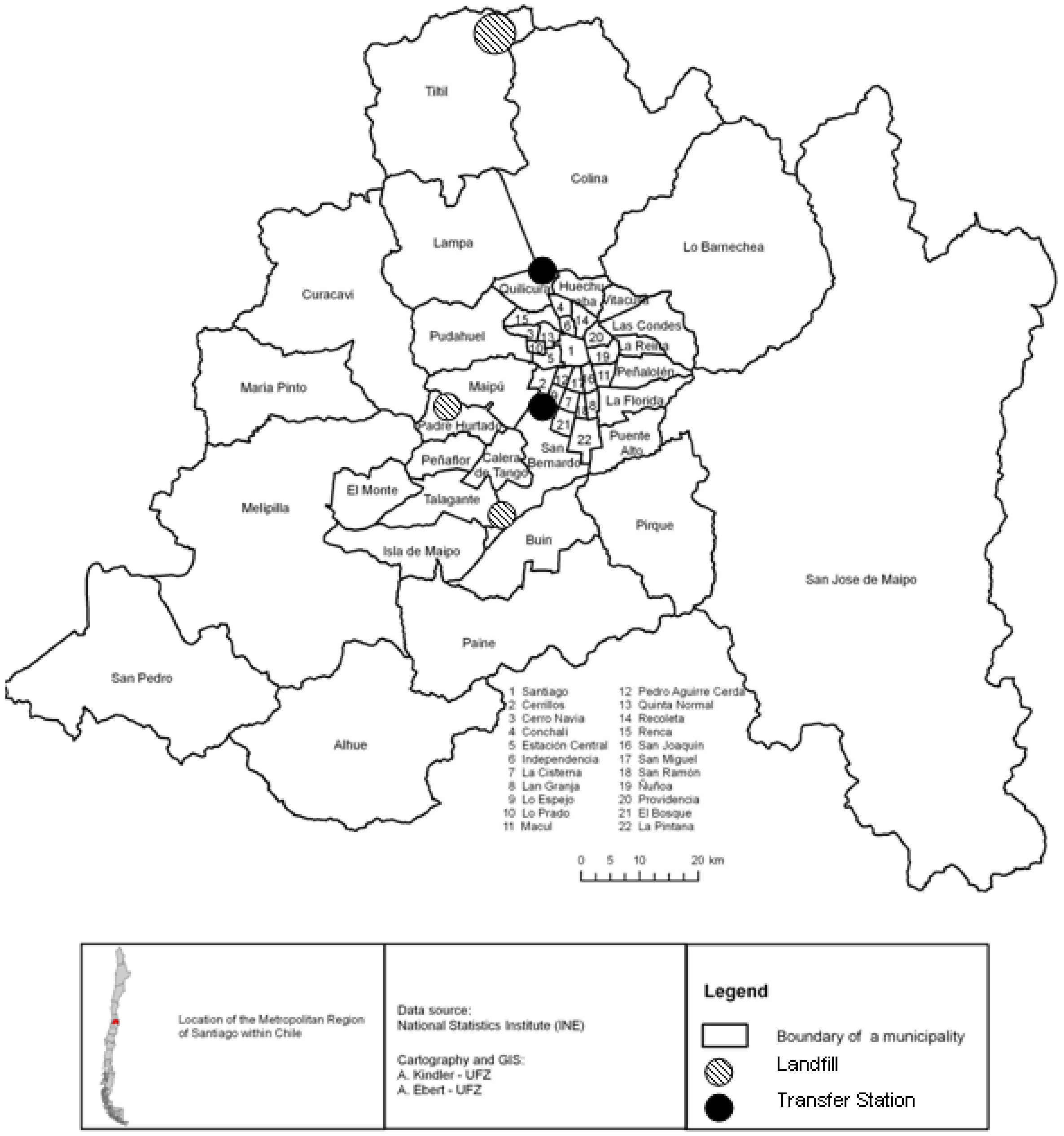


Figure 4.4 Landfills in the MRS (SESMA undated)

4.4.2.2 Santa Marta landfill

Santa Marta (Figure 4.6) is the second largest of the three disposal sites in operation; it is located in Talagante, 12 km south of Santiago downtown. Santa Marta is managed by “Consorcio Santa Marta”, it was opened in 2002 and will continue landfilling until at least 2022, when the contract ends, although landfill capacity estimates predict an extended operation time. The current landfill input rate is approximately $700 \cdot 10^3$ Mg/year, which accounts for 29% of total MSW disposed of in landfills. Roughly 80% of the waste disposed of in the landfill is received at the transfer station “Puerta Sur”, with direct discharge and no compaction, and subsequently transported to the landfill site in special containers. Landfill gas is flared by five flare stacks, with a capacity of 1,000 m^3 per hour each (CDM 2006b, Wens 2008). Leachates are collected and treated, by an anaerobic and aerobic processes, adsorption with activate carbon and sedimentation.

4.4.2.3 Santiago Poniente landfill

The landfill Santiago Poniente (Figure 4.7) is managed by the French-Spanish group "Proactiva Chile" and it is the smallest of the three landfills operating in the MRS. Santiago Poniente is located in the municipality of Rinconada de Maipú. It started operations in October 2002 and shows a current filling rate of approximately $300\cdot10^3$ Mg/year, which accounts for 15% of the MSW disposed of in Santiago de Chile. It is expected, that the landfill will reach its lifetime around 2025. There is no a transfer station associated with the landfill Santiago Poniente. The operating company of the landfill was recently given environmental authorization for landfill gas capture and flaring. Additionally, leachates are collected and treated in open air pools (CONAMA 2001a, Mundo Proactiva 2009).

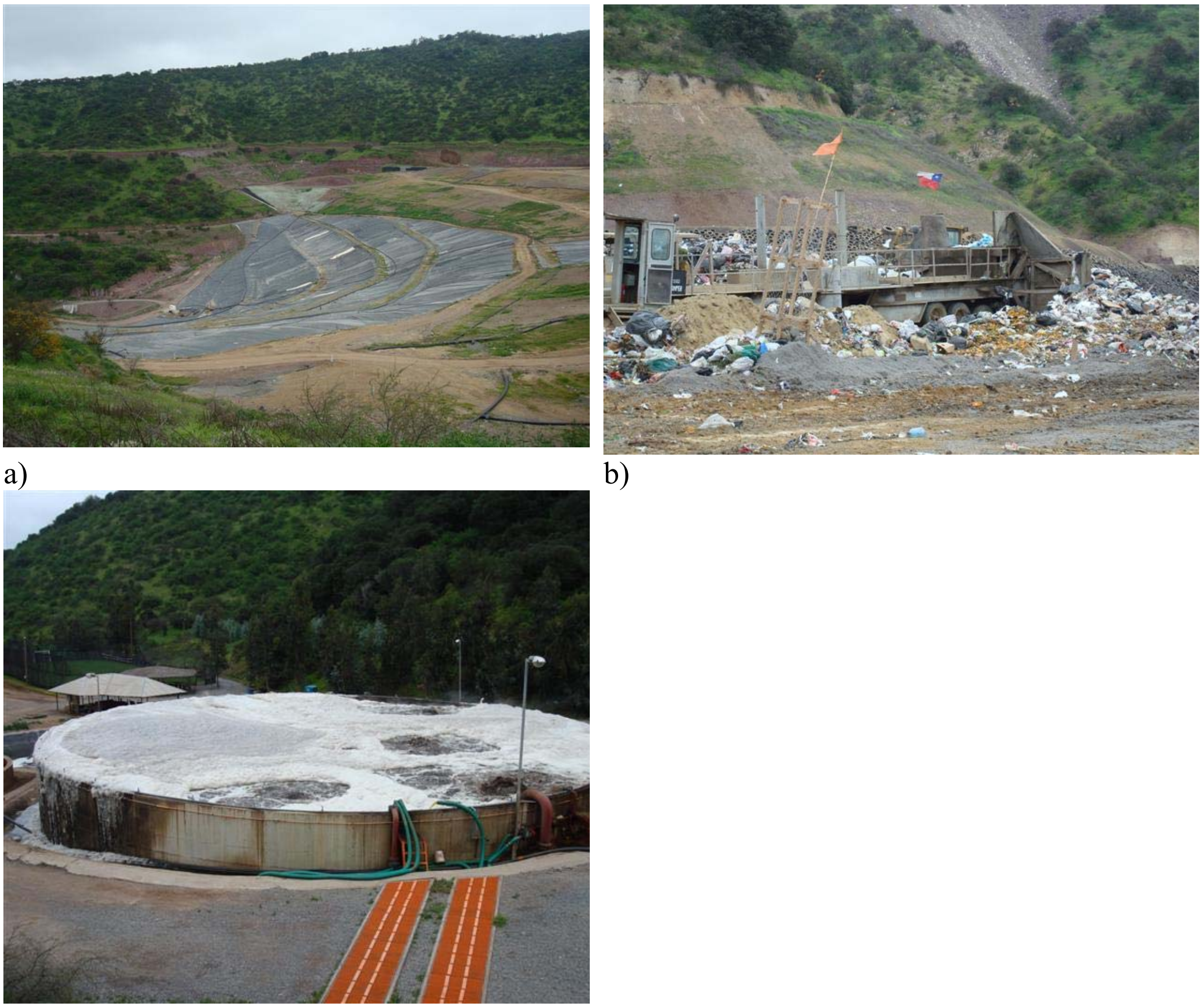
a)

b)

Figure 4.5 Landfill Loma los Colorados (background research 2007)
a) Compaction of MSW b) Biogas collection system and flare chimney

4.4.3 Recycling

Even though, recycling has been taking place in Chile since 1970 (Alaniz 1998, Szantó 2006), its status is still undeveloped. Moreover, it is not mandatory to separate recyclables from the mixed MSW in Chile, thus the legal framework does not create an environmental recycling awareness among the citizens. In 2005, a first recycling strategy for the MRS was developed by the CONAMA, with the aim of achieving a recycling rate of 20% in 2006. However, according to official data, the recycling rate was in this year 13.9% (CONAMA 2005a, 2009). This fact puts in evidence lack of awareness in the population, the necessity to improve the linkages among important key stakeholders and to develop concrete technical proposals, to achieve specific recycling goals. In 2009, a new goal has been established by CONAMA, namely to achieve a recycling rate of 25% in 2020 (CONAMA 2008, 2010).



a) b)

c)

Figure 4.6 Landfill Santa Marta (2009)
a) Landfill overview b) Waste compaction c) Leachate treatment

a) b)

Figure 4.7 Landfill Santiago Poniente (background research 2007)
a) Leachate pools b) Biogas collection

One of the main objectives of the field research carried out in Santiago de Chile from May to July 2008 was to identify and describe the MSW recycling systems in the Metropolitan Region of Santiago (Figure 4.8). In recent years, some municipalities have introduced formal recycling activities and have included recycling programs to cover composting, segregated collection and drop-off systems for certain residues. Activities organized by the municipalities include education campaigns. The aim of these campaigns is to enhance awareness of the environmental benefits of recycling practices.

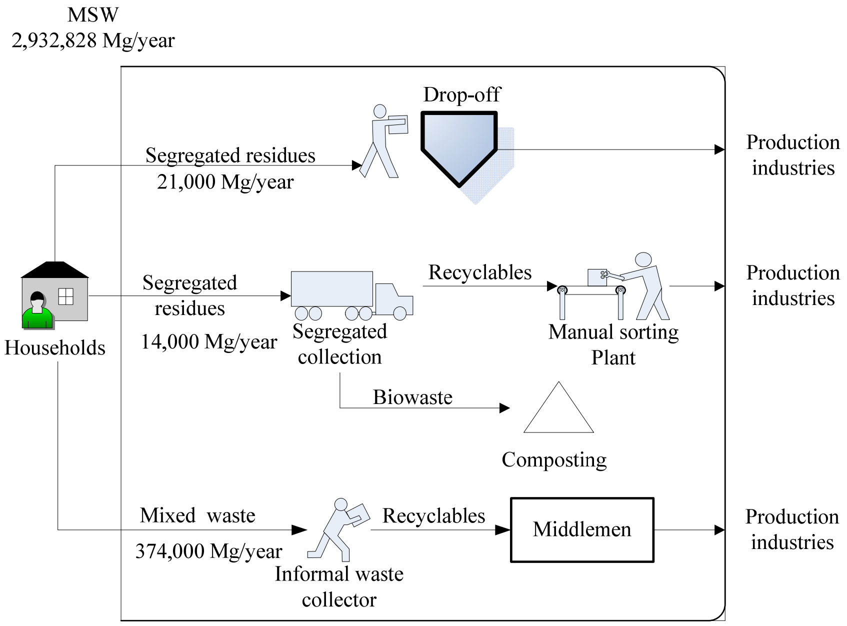


Figure 4.8 Recycling systems in the Metropolitan Region of Santiago

Noteworthy, that most of the recycling is accomplished as an informal activity, performed by independent, non organized groups of people, called in Chile “cartoneros”, “cachucheros” or “recolectores”. They collect valuable materials from the streets of residential and commercial zones, use tricycles as transport and working tools. They separate and classify the materials, improving their monetary value in the process, and sell them to middlemen who deliver them to production companies as secondary raw materials. The status of middlemen varies between formalized and informal commercial groups.

4.4.3.1 Publicly organized systems

Publicly organized recycling activities haven been introduced by a few municipalities in Santiago de Chile. The schemes differ for the most part, on how MSW is collected and they are classified in curbside collection of source segregate materials and in drop-off systems. Participation in both systems is voluntary. Brief information about the municipalities which have recycling programs is given in Table 4.3.

4.4.3.1.1 Collection of source separated materials

In segregated collection schemes citizens are encouraged to separate their recyclable materials, which are collected by a different collection truck. During the field research carried out in Santiago de Chile, it was identified that differentiated collection systems exist in the municipality of La Pintana (biowaste), Ñuñoa, La Florida (recyclables), María Pinto (biowaste and recyclables) and Vitacura (biowaste and recyclables). Hence, only less than 10% of the 52 municipalities of the MRS have introduced segregated collection of solid waste. Figure 4.9 shows some of these facilities.

The total quantity of recyclable materials collected by the publicly organized systems corresponded to approximately 4,000 tons in 2007. This quantity is almost negligible in comparison with the 2.5 million tons of MSW sent to landfills each year. Nevertheless, if seen as individual initiatives, they can be analyzed to identify weakness and strength of this kind of systems.

Table 4.3 Municipalities with recycling programs in the MRS (field research 2008)

Municipality	María Pinto	La Pintana	La Florida	Ñuñoa	Vitacura	
Population[a] (2007)	11,376	201,638	396,575	152,887	81,251	
Monthly household income[d] [US$]	630	830	1,900	3,000	6,500	
Area [km²]	395	31	71	17	29	
Waste deposited in landfills [Mg/year; kg/(person·day)] (2007)[b]	2,437[c]; 0.59	59,905; 0.81	145,913; 1.0	69,902; 1.3	48,241; 1.6	
Recycling program	Segregated collection, including biowaste	Segregated collection of biowaste and reuse	Segregated collection	Segregated collection, separation, compacting, shredding	Drop-off center	Segregated collection
Started	1998	1996	2005	2003	2006	2007
Brief description	Materials are classified and sold by one private company Organics are composted in windrows	Composting in windrows and with worms	Collection, classification and selling by private company There is no infrastructure associated	Manual sorting is carried out in a materials recovery facility	“Clean Point” Six underground containers, and six superficial containers	It covers only two sectors of the community
Source of materials	Household, (rural), markets	Household, markets	Household, commercial	Household, Commercial	Household,	
Frequency of collection	1 day/week	Every other day	1 day/week	1 day/week		Once every two weeks
Total quantities (2007) [Mg/year]	Inorganic: 326 Biowaste: 672	9,640	539	2,220	360 820 (including bulky waste)	975
Calculated recovering rate [%]	17.3	13.9	0.4	3.1	2.4	2.0

Sources: a: INEa b: SEREMI RM c: Mualim 2006 d: Mideplan 2007

The calculated recycling rate for the municipalities executing segregated collection varies from 0.4% in La Florida to 17.3% in María Pinto. This rate was calculated on the basis of the total quantity of materials arriving at the landfills, quantity published by the Health Ministry of Chile and the quantity of recyclables obtained during field research.

As observed in Table 4.3, the flux of MSW sent to landfills correlates with the monthly income of each municipality. The lowest value (0.59 kg/(person·day)) and US$ 630 per month respectively) is found in Maria Pinto and the largest one in Vitacura (1.6 kg/(person·day)) and US$ 6,500 per month respectively). In contrast, the largest recycling rate (17%) is obtained in the rural municipality of Maria Pinto, where the implementation of publicly organized recycling systems has a stronger effect in the recycling rate.

a) b)

c)

Figure 4.9 **(field research 2007-2008)**
a) Materials recovery facility in Ñuñoa b) Collected materials in María Pinto
c) Composting plant La Pintana

The example of La Pintana is also interesting, because in this municipality only biowaste is segregated collected, however a relatively high recycling rate is achieved. This result puts in evidence the importance that the organic fraction of the waste plays in the management of the residues in Santiago de Chile.

In Ñuñoa, the goal of the material recovery facility is to collect and to recycle 10% of the waste generated. The design capacity of the plant would allow collection and separation of materials up to 500 Mg/month, nevertheless the participation of the householders is low, and the plant is operating below its design capacity.

The low recycling rates can be attributed to the low participation of citizens, despite the education campaigns which are continuously taking place on those communities, together with recycling programs (field research Santiago 2008). Another factor is the low collection coverage, for example in La Pintana, Vitacura and María Pinto, the separate collection does not cover the whole municipality. Additionally, inadequate source separation by householders is another important factor. In the Ñuñoa plant for instance, 30% of the residues collected do not correspond to recyclable materials (field research Santiago 2008).

4.4.3.1.2 Drop-off systems

Drop-off systems are organized by production companies and charity foundations. Because recycling in Chile is voluntary, the participation of the citizens in this kind of program is highly encouraged. A few production companies offer money to charity institutions, according to the amount of secondary raw materials collected. The scheme consists of containers situated in public places, such as churches, grocery stores, and private dwellings, where citizens deliver their recyclable materials. For the year 2007 collection from drop-off containers, amounted to about 21,000 tons of waste (Table 4.4).

Table 4.4 Production companies associated with recycling - charity campaigns (2007)

Material	Amount* [Mg/year]	Production company	Charity institution
Paper, cardboard	6,600	SOREPA S.A. Recupac	Fundación San José Hospital de Niños Roberto del Río
PET bottles	300	Recipet S.A.	Cenfa
Aluminum cans	70	Copasur Latasa S.A	
Glass	13,800	Cristalerias Chile Cristalerias Toro	Coaniquem Codeff

* These data is based on surveys carried out in communes with recycling programs, during field research and own estimations

One example is the "Clean Point" ("Punto Limpio") in the municipality of Vitacura (Figure 4.10), a modern facility, where containers have been set up in an area of 500 m² for the collection of paper, cardboard, plastics, ferrous and non ferrous metals, yard waste, batteries and old medicines. The "Clean Point" is located in a high income area, it has been largely accepted by neighbors, and statistics show an increase in the yearly quantity collected of 25% (interview with Araya 2008, Bravo et al. 2009).

The quantity of materials collected by drop-off systems is about five times higher than the recycling material from collection of segregated materials. This statement could be attributed to the fact that drop-off containers have been set up throughout the MRS, whereas differentiated collection takes place on a smaller scale, in less than 10% of the municipalities of the MRS. In addition, drop-off systems in Chile do not only contribute towards the protection of the environment, but the system largely encourages the social-charity factor, associated with donations to involved charity institutions.

Figure 4.10 "Clean Point" Municipality of Vitacura (field research 2008)

4.4.3.2 Informal systems

In this Section, an overview of the informal waste sector in Santiago de Chile is briefly described. A more extensive analysis of the sector is given in Chapter 6.

A large informal waste sector is present in Santiago de Chile. Unofficial estimates indicate that between 4,000 and 15,000 people work as primary collectors in the city, using tricycles as transport and working tools (Astorga 2008, Alaniz 2009).

According to (Florisbela and Astorga 2006) the informal waste sector in the MRS forms an interconnected chain with two main actors:

- Primary collectors: a large group of people who work informally on the streets of Santiago de Chile, collecting valuable materials out of trash bags and bins. Usually, they leave organic materials at the source, taking the rest to their own homes for further separation. When enough quantities of materials are collected, these are sold to middlemen.
- Middlemen: this group of people has larger collection capacity than the primary informal collectors; if they collect recyclables they generally use motor vehicles. Moreover, they own stock centers where materials can be further classified and processed, maintaining quality requirements established by industries. Middlemen are able to gather a larger quantity of recyclable materials, and sell it to production companies, obtaining a better income than the primary collectors.

The role played by the informal waste sector in the MSW management of Santiago de Chile relates directly with recycling. 4,000 Mg per year of recyclable materials are collected by formal segregated collection systems (Table 4.3) and 21,000 Mg/year by drop-off systems (Table 4.4). But, it is the informal sector that is collecting and processing nearly 375,000 Mg/year of materials which do not end up at landfill sites.

Figure 4.11 compares the total quantity of recyclables found in solid waste flows, with actual recycled flows (collected by the informal sector and by drop-off systems). The largest amount collected by the informal sector corresponds to paper and metals. It is observed, that the total quantity recycled, nearly equals the quantity collected by the informal sector for paper, metals and plastics. The situation is different for glass, because a large number of glass containers have been set up throughout the MRS (SINIA 2008), for more than ten years, with a strong information and awareness campaign.

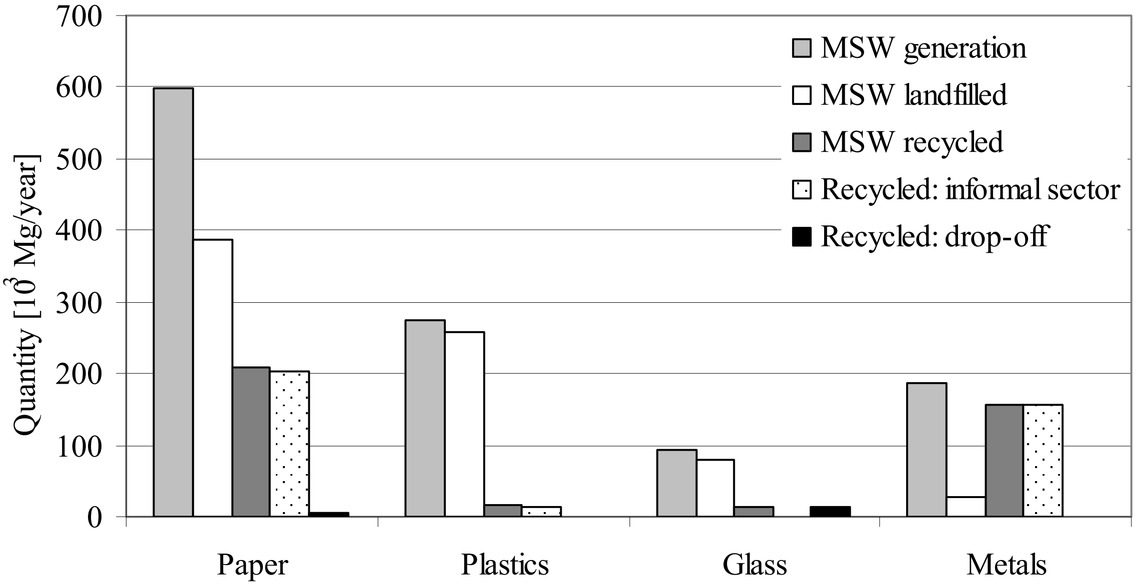


Figure 4.11 Recyclable materials flows - MSW informal systems, drop-off systems 2007

4.4.3.3 Recycled products

4.4.3.3.1 Paper

There are 11 paper mills in Chile, the largest being the "Compañía Manufacturera de Papeles y Cartones" (Manufacturing Company of Paper and Cardboard) (CMPC S.A). The CMPC utilizes paper as secondary raw material in its production processes. Paper recovery is carried out by SOREPA, company that belongs to CMPC. SOREPA is in charge of paper collection, classification, preparation and transport to final buyers, including associated costs. Paper is usually bought from informal collectors, supermarkets, malls, and offices (Florisbela and Astorga 2006).

A large number of people participate in the informal collection and recycling of paper. The stock centers buying paper and cardboard are the largest in number in Chile. A recent study showed that 82% of informal workers in Santiago de Chile collect paper and cardboard (Valenzuela et al. 2010). The chain of paper recycling is formed by primary informal collectors, middlemen, stoking centers, like SOREPA, and paper mills. In the stock centers materials are usually packed, shredded, and crushed.

4.4.3.3.2 Glass

"Cristalerías de Chile" and "Cristalerías Toro" are companies promoting glass recycling in Chile, through drop-off systems and charity campaigns. These two companies own about 90% of the Chilean glass market.

The number of informal glass collectors and middlemen is smaller than those for paper, cardboard, and scrap. According to (Valenzuela et al. 2010, Florisbela and Astorga 2006) 34% of the interviewed workers collect mixed materials, including a small fraction of glass, but only as a complement to other materials.

4.4.3.3.3 Plastics

The recycling sector for plastics in Chile is also at its beginning and the existing capacity for plastic recycling is not completely used (GTZ 2006b), there are only a few companies recycling plastics in the country.

As a way to improve and motivate plastics recycling, in 2006, a public-private project organized by the GTZ, the Universidad de Concepción, and German and Chilean plastic companies developed a logistic system for the collection and recycling of plastics in Chile, including the active participation of informal collectors. The project identified several obstacles, such as lack of responsibility from plastic packaging producers and logistic problems, associated with volume and quality of plastic residues (interview with Reinhard 2008), which difficult to maintain a constant flow of secondary plastics for the recycling companies.

The informal collectors do not often collect plastics, because of its low density. Plastics are also collected as a complementary material. The only material of interest corresponds to post consumption PET bottles, because of its high commercial demand and relatively easy recycling process (Florisbela and Astorga 2006). Middlemen collecting plastics, often improve the monetary value of the materials, by executing cleaning, crushing or pelletizing processes.

4.4.3.3.4 Scrap and aluminum

About $300 \cdot 10^3$ Mg/year of scrap are recycled in Chile. The largest scrap consumer in Chile is the company Gerdau AZA. This company has promoted scrap recycling in recent years, with a large participation of the informal primary collectors. According to (Valenzuela et al. 2010) 74% of primary collectors gather scrap. Middlemen in the scrap chain usually own a recovery center and buy scrap from primary collectors. Generally, non ferrous metals are exported, whereas ferrous metals are traded within the country, to companies such as Gerdau AZA or Comec. Middlemen use shredders and in some cases cutting machines.

Aluminum is collected in the same way as the ferrous metals, but its recycling process takes place outside of Chile, because of volume and technological limitations (Florisbela and Astorga 2006).

4.5 Economic Aspects of the MSW management in Metropolitan Region of Santiago

4.5.1 MSW management costs

The total budget that the municipalities in Santiago de Chile allocated to the MSW management service in 2007 was approximately US$ 105 millions, this value includes costs of waste treatment incurred by the municipality, payments to private companies in charge of waste collection and disposal costs. The costs of the MSW management service in the MRS are shown in Table 4.5.

Table 4.5 Costs of the MSW management in the MRS (SINIM, Godoy and Ossadon 2009)

	Collection [US$/Mg]	**Transfer station [US$/Mg]**	**Landfilling [US$/Mg]**	**Total costs (landfills with transfer station) [US$/Mg]**	**Total costs (landfills without transfer station) [US$/Mg]**
Average	26	7	11	42	41
Minimum	10	3	3	20	19
Maximum	60	15	18	75	58

The low costs of landfilling can be partially explained because costs of closure, maintenance and monitoring, as well as collection and treatment of leachate and biogas after closure are not included in the calculation of the waste management tariff (Mideplan 2010). In the European Union, on the contrary costs associated with after closure measures, such as re-vegetation of the landfills or slope stability control are considered in costs calculations.

4.5.2 MSW management fees

The degree of solid waste management costs recovery depends on the income received by the municipalities from users payment, associated to waste management. In Chile, this income is a function of the *waste management service tariff* and the *total quantity of urban residence premises and commercial premises* having access to waste management services.

4.5.2.1 MSW management tariff

Currently, municipalities are authorized to finance the MSW management service through a solid waste management tariff, according to Equation (66):

$$Tariff = \frac{\sum Cost^{MSW}}{\sum P_{res} + \sum P_{com}} \qquad \textbf{Equation (66)}$$

Where:

Tariff: MSW management tariff

$Cost^{MSW}$: incurred costs of MSW management

P_{res}: urban residential premises

P_{com}: commercial premises

It should be noted, that the tariff varies among municipalities in the MRS, but the calculation does not correlate with the amount of MSW generated by householders within a municipality, and the calculation is based in previous expenditures and not in projected costs.

4.5.2.2 Urban residence premises and commercial premises

Through the enactment of the Law No. 19,388 in the year 1995, the financing system for the MSW management in Chile was affected significantly. This law enabled the municipalities to collect fees for MSW management from all urban residential premises. According to this law, those users whose premises had a fiscal value below or equal to 25 monthly tax units[11] (MTU) were absolved from paying the waste management service (CCI 2008). Before the establishment of this law, the charge for waste management fees was possible only to properties that were subject to the payment of land tax. Therefore, this law allowed municipalities to extend the charging of fees to a larger number of properties, through direct mechanisms. Additionally, large producers (more than 60 liter of waste daily) are charged a special tariff.

In 2005, the Municipal Revenue Act was established. With this Act the range of exemption of charging fees was shifted, absolving users from payment of the fee, if the tax assessment on their premise was below 225 MTU (CCI 2008). Consequently, the number of exempted properties increased (Figure 4.12).

Even though, the MSW management tariff is not directly related with the quantity of MSW produced within a municipality, if the whole MRS is considered it is clear that municipalities producing larger waste quantities per capita, will have larger costs and therefore a more expensive tariff. In Figure 4.13, the fraction of premises exempted for waste management fees in the MRS is depicted. Additionally, the income fraction that is not received by the municipalities, because of the exemption shown in Figure 4.12, is also given. As observed, the fraction of absolved properties has a lower impact on the income fraction perceived by the municipalities.

Figure 4.14 shows the fraction of properties exempted from paying municipal waste services in the municipalities of the MRS. As observed, the middle to high income municipalities, like Las Condes, Ñuñoa, Providencia, Santiago and Vitacura have a larger percentage of non absolved properties. Additionally, Lo Bernechea, La Reina and San Miguel, which are medium to high income municipalities, show also a larger percentage of properties no exempted from payment. Therefore, in these communities it is possible to have a larger costs recovery, and in theory offer a better MSW management service. On the contrary, those communities with more absolved properties are the poorest ones. In the MRS, the total amount of properties corresponds to 2,324,669 (SII undated), of which 1,244,169 were exempted from payment (53.5%) and the rest 1,080,500 (46.5%) properties had to pay the MSW management fees.

4.5.3 Recovery of MSW management costs

In addition to direct charging fees, two other mechanisms exist to recover MSW management costs in Chile, these are the *land tax* and the *commercial municipal license*. The land tax is paid, as mentioned above, by those premises with a MTU value above 465. The commercial municipal license is paid by premises accomplishing lucrative activities, in this case the waste management fees are paid together with the commercial permit.

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[11] MTU is an account unit used in Chile, for tax purposes and fines, update for inflation, the average value in 2007 was 32,906 Chilean Pesos (US$ 63)

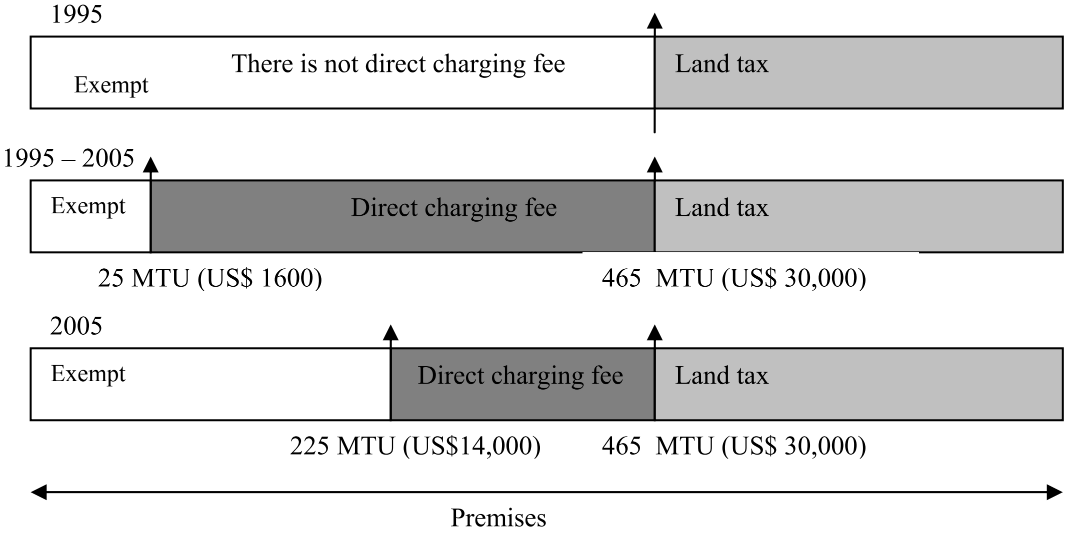

Figure 4.12 Exemption evolution for waste management fees (CCI 2008)

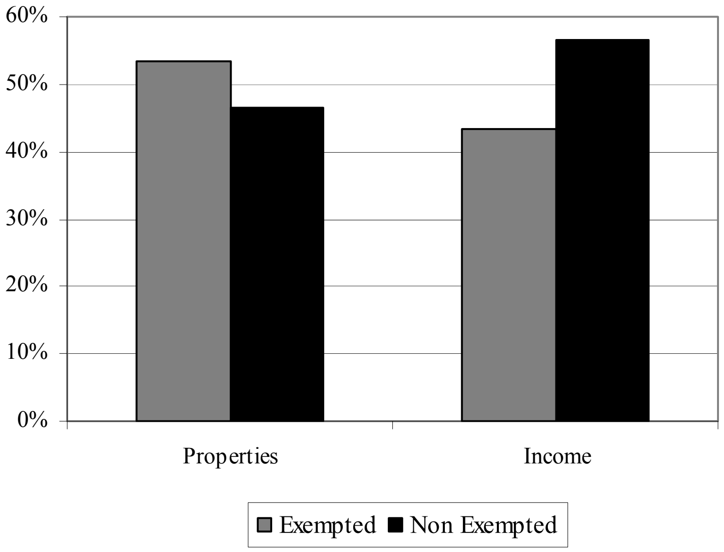

Figure 4.13 Fraction of premises exempt from paying the MSW management tariff and income impact

In 2007, the land tax contributed with 58% to the total income of MSW management services, and the rest was obtained through direct fees and municipal license. Even with the application of these three charging systems, it is not possible to recover the total costs of the MSW management in Santiago de Chile, which in average is roughly 51%. The degree of costs recovery in all the municipalities of the MRS is given in Annex A.

As mentioned above, in the MRS, approximately 53.5% of the properties are exempted of direct payment of waste fees (Figure 4.13), this value influences the degree of costs recovery (Figure 4.15). Another reason to the low recovery rate is given because from those non-absolved properties, there is a fraction which does not pay these fees (CCI 2008). Additionally, the tariff charged does not correspond exactly with costs of waste management, but with the expenditures from the previous year (CCI 2008), and in several cases the municipal management system does not provide a breakdown of the real costs of their MSW management, impeding appropriate tariff estimation.

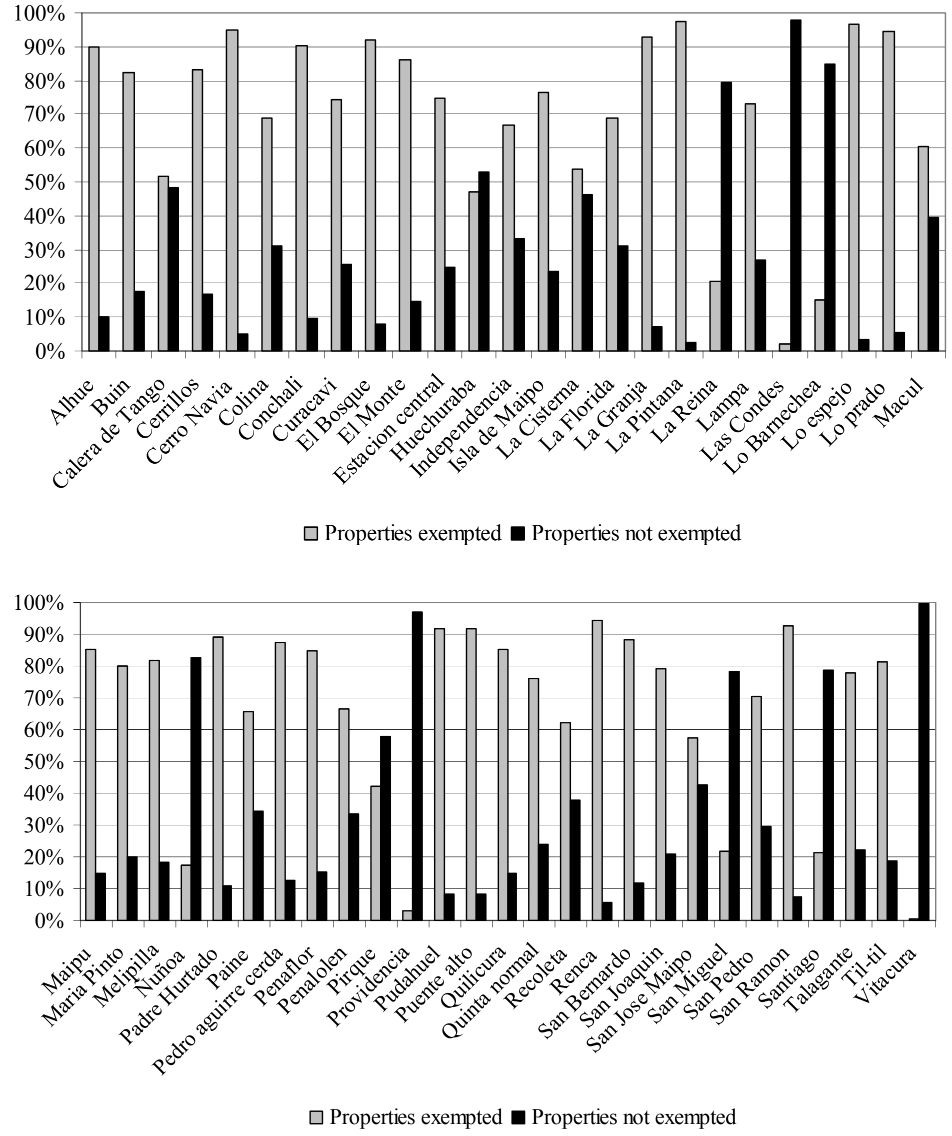

Figure 4.14 Properties exempt from paying MSW management fees, 2007 (SII undated)

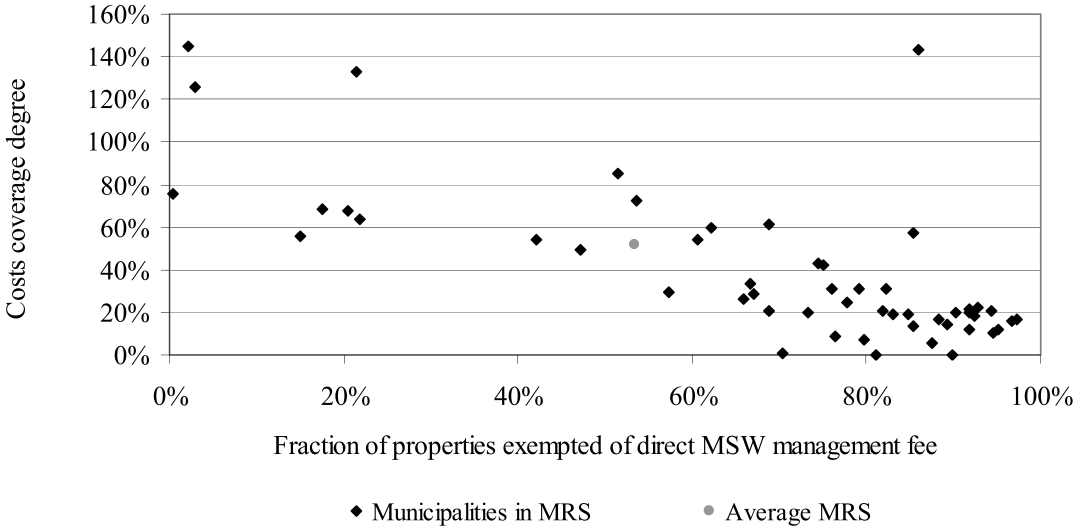

Figure 4.15 Relation between properties exempted from paying the MSW management fees and degree of cost coverage , 2007 (SINIM, SII undated)

4.6 Identified Challenges of the Municipal Solid Waste Management in the Metropolitan Region of Santiago

The analysis of the current MSW management in the MRS indicates that since the implementation of the Environmental Impact Assessment System in 1997, there has been considerable progress in the collection and final disposal of MSW. Nowadays, collection services are provided nearly in the whole MRS.

Nevertheless, the largest fraction is disposed of at sanitary landfills. The biogenic fraction of the total MSW in Santiago de Chile accounts to almost 50%. The decomposition of this fraction is accompanied by landfill gas emissions and the production of leachate over a long time (Clauß 2006). Landfill gas emissions contribute to global warming, while leachates are a source of groundwater contamination, having thus an impact on public health and local and global environment.

The growing quantities of MSW and low recycling rates are additional problems and they suggest a deficient management in terms of resource efficiency. Most recycling is carried out by people from the informal sector. In Santiago de Chile, there is a recycling market for paper, cardboard, glass, aluminum, and scrap, therefore because of the labor of the primary collectors these materials do not end up in landfills and re-enter the resources cycle, impacting the Chilean economy and providing at the same time a solution and a livelihood for the informal collectors involved. Nevertheless, people working in the informality lack of working contracts, working rights or health insurance. Moreover, people in the informal sector are not yet considered as important actors of the MSW management system in Santiago de Chile. Moreover, there is lack of laws and binding policies addressed to increase the demand for recycled products, environmental sensitivity and awareness of the population. The weak capacity of the municipalities to recover the cost of MSW management is another identified deficit, in average the municipalities of the MRS manage to finance only 51% of these costs and there are only four municipalities financing 100% of the total services costs.

There is consequently, a challenge for the implementation of adequate treatment technologies, enclosed by mechanisms allowing a better financial management and reducing economic, social and environmental costs.

Outlook

The identified challenges corresponded to the MSW management situation in 2007. Between 2007 and 2010 three waste management scenario workshops and conferences with participation of stakeholders were held in Santiago de Chile, within the framework of the Risk Habitat Megacity Project and this research work. In these three years, the waste management situation in the MRS has improved. Of special importance is the preparation of a general Waste Law, whose draft will be released at the end of November 2010. This law will include following aspects (CONAMA undated):

- Establish a legal framework, based on a hierarchical approach, promoting the prevention of waste generation, in the first place, followed by waste reduction, reuse, recycling, energy recovery, and final disposal.
- Develop regulations related to Extended Producer Responsibility. The regulations apply to consumer products such as containers, tires, refrigerators, vehicles, batteries, oil and electronics, among others.
- Give a definition of responsibilities between the bodies which regulate and monitor waste legislation.

Moreover, during the second half of the year 2010, it is being discussed if and how the informal primary collectors will be considered within this Law, and included in the definitions of MSW management systems (Alaniz 2010, personal communication with Exequiel Estay).

Chapter 5

Sustainability Assessment of Municipal Solid Waste Management in the Metropolitan Region of Santiago

In this Chapter, the results of the sustainability assessment of the current management of municipal solid waste in the MRS are presented and discussed. For the evaluation, selected indicators of sustainability were chosen; current status of these indicators and the decisive factors for the establishment of target values for Santiago de Chile in 2030 are additionally given.

5.1 Selection of Sustainability Indicators for MSW Management

Several research studies assessed megacities as risk areas, arguing that these urban habitats pose injuries and damages to people living there (Kraas 2003, Pelling 2003). Within the field of MSW management in Santiago de Chile, risk is defined as the danger of not attaining sustainable development goals, defined by means of target values of indicators of sustainability.

The Integrative Sustainability Concept provides a framework to define indicators of sustainability for MSW management in Santiago de Chile (see Section 2.3). The analysis of the current situation of MSW management, the identified challenges and the criteria given in Section 3.2.1, led to choose the sustainability indicators presented in Table 5.1. At the same time, these indicators refer to the guidelines of sustainable MSW management presented in Section 2.3.

Table 5.1 Selected indicators to evaluate the MSW management in Santiago de Chile (based on Seidl 2008)

Waste Management Guideline	Indicator
Maintaining the regeneration capacity of natural systems	Specific waste generation [kg/(person·day)] Quantity of pretreated mixed waste to reduce organic carbon content, in relation to total mixed waste [%] Greenhouse gases associated to MSW management [kg CO_{2eq}/(person·year)]
Sparing use of renewable and non renewable resources	Waste fraction recovered as material or energy [%]
Guaranty of safe disposal	Remaining life time of adequate waste treatment and disposal facilities [years]
Organization of the waste management system to justifiable overall economic costs for a fairer development	MSW management costs recovery [%] Fraction of gross domestic product spent on MSW management [%]
Guaranty of the possibility of independent existence, which fulfills the basic needs and creates opportunities for development	Income level of primary collectors in relation to household income [%]

In the next paragraphs for each indicator of sustainability, the current situation in the MRS is briefly described, together with identified causes leading to this situation. Moreover, associated negative impacts of current values of indicator are pointed out, in addition to reasons guiding the selection of target values.

5.1.1 MSW generation in per capita terms

The use of resources is the backbone of any economy, but in using and transforming natural resources solid waste is produced. Excessive waste is a consequence of resources loss in the form of materials and energy and this may be an indicator of inefficient production processes, poor durability of goods or unsustainable consumption patterns. Additionally, there are other factors influencing the quantity of solid waste generated such as geographic location, season, habits and economic status of the population, legislation and public attitude (Tchobanoglous 1993).

The quantity of waste generated per capita in the MRS has increased nearly 45% in recent decades, being in 2007 roughly 1.2 kg/(person·day). This constant growth is essentially a consequence of Chile's economic development during the last decades (see Figure 4.2). The Chilean legal framework is deficient in terms of political measures to prevent waste generation and strategies to minimize it (Szantó 2006, CONAMA 2005b). Without incentives, it seems logical that specific waste production will increase even more.

Large quantities of MSW bring as consequence a rise in the collection frequency, with associated air emissions (carbon dioxide, nitrous oxide, fine particle matter), traffic congestions, acquisition of new collection trucks, turning out in higher costs.

Additionally, in the case of Santiago de Chile, roughly 86% of the total quantity of waste produced is disposed of in landfill sites. Therefore the landfills lifespan is reduced, creating the necessity of searching for new sites, leading to land consumption and costs for new disposal facilities. In addition, considerable quantities of greenhouse gases are emitted from the landfills in the MRS, even with the introduction of systems for capturing landfill gas. Furthermore, landfill gas emissions impact on global climate and methane emissions can cause fires and explosions. In addition, landfill leaks carry the risk of groundwater contamination. If groundwater is used for irrigation or the production of drinking water, the impact on people's health is negative.

These negative impacts represent a risk against the *regeneration capacity of natural systems* and the *guaranty of safe disposal,* which are important rules of sustainability according to the Integrative Sustainability Concept.

International trends were analyzed within this work, in order to define a target value for this indicator. These trends indicate a shifting towards waste prevention. For example in the European Union and in the USA, it is aimed to decouple the use of resources and generation of waste from economic growth (Eurostat, 2008, Scheinberg 2008). The west European solid waste management system is highly advanced compared with that of Chile. One of the principles of the European Union's approaches to waste management is based on waste prevention. This means to reduce the amount of waste generated in the first place and to reduce its hazardousness or toxicity in the second place.

In Figure 2.2 b, the GDP was selected as economic parameter influencing waste generation. The upper level of waste generation corresponds to approximately 2 kg/(person·day). This level is reached by the most prosperous countries. In comparison, the quantity of MSW produced in Germany, a country with a host of regulations and incentives for waste reduction, is 1.6 kg/(person·day) (Statistisches Bundesamt 2009), lower that might have been expected in light of its economic prosperity. In Berlin the value comes to 1.4 kg/(person·day) (BSGUV undated). Both figures refer to the year 2007.

It is therefore suggested, that MSW management concepts for Santiago de Chile seek to move from a position of high waste production to one that minimizes waste generation, lowering the rate of waste generation per capita, even with economic development. Therefore, it is suggested to maintain a MSW generation flux below 1.6 kg/(person·day).

5.1.2 Amount of mixed waste pretreated to reduce organic carbon content in relation to total mixed waste

The landfilling of mixed solid waste with a high biogenic content produces greenhouse gas emissions and leachates, which are harmful to the environment and human health. Even with the use of seals, these emissions cannot be contained in the very long term, and monitoring, collection and treatment must be carried out for several years after landfill's closure.

One alternative to improve and prevent this situation is to pretreat MSW before deposition in landfills. The aim of this treatment is to reduce the mass and volume of the waste, and its harmful effects on the environment. The pretreatment processes include mechanical-biological and/or thermal processes. The selection of the appropriate technology depends on waste quality, management conditions, and economic, ecological and social factors.

Currently in the MRS, solid waste is sent to landfills without mechanical, biological or thermal pretreatment, and there is a lack of laws and policies regarding pretreatment of MSW in Chile. A possible cause for this situation is the fact that financing entities, such as the Secretary of Regional Development (SUBDERE) approve credits for projects aiming at the closure of old dumping sites, or for improvement of technical standards in landfills, leaving aside projects to encourage alternative waste treatments (interviews: Alaniz 2009, Eyzaguirre 2010). Moreover, the low prices of landfilling make the implementation of substitute waste management technologies unattractive.

If pretreatment of MSW does not take place, large waste quantities need to be disposed of, hence transfer stations and landfills have to be built and operated, resulting in land consumption, higher costs, and health impacts for employees caused by different contaminants, noise exposure for employees and for residents.

Moreover, large quantities of methane and carbon dioxide, within the landfill, are associated with the decomposition of the organic fraction of the MSW that is not treated before disposal. The negative effects of these emissions were mentioned in Section 5.1.1. Additionally, because of the long time span for methane formation, landfills have to be controlled after their closure. Formation of methane and carbon dioxide will continue having an impact on global climate, and the risk of groundwater contamination will increase, caused by a larger probability of leakages from the landfill after long time periods. In addition monitoring of landfills after closure also implies higher costs.

The negative impacts associated with lack of pretreatment of mixed MSW put at risk essential sustainability rules, in particular the *ability of self-regeneration of natural systems*, the *minimization of adverse health impacts caused by the environment* and the *guaranty of safe disposal.*

The pretreatment of MSW is a concept originated from the European Landfill Directive, which states, among other matters, that all waste accepted in landfills, including all non hazardous waste, must go through a pretreatment process before. The landfill guideline 1993/31/EG instructs European Union member states, to reduce the organic fraction of MSW brought to landfills, within a period of 15 years. In Germany, final disposal at landfills is now limited to solid waste with a total organic carbon of not more than 3%. Additionally, special limit values for organic waste that has been subjected to mechanical biological treatment were introduced. Since 2005 in Germany, the amount of landfilled municipal solid waste dropped to one percent of residual waste.

In Latin America, a few experiences with experiments and pilot plants for pretreatment of MSW through mechanical biological treatment (MBT) have taken place in Brazil and Chile

(Münnich 2006, 2009, GTZ 2003). These practices show the suitability of MBT process to improve the landfill behavior in the communities where it was tested. However, its implementation requires training and external supervision, as well as structural changes in the involved waste management system. Nonetheless, these examples provide a good starting point for further research.

Ideally, it should be enforced to pretreat 100% of the mixed MSW brought to landfills, however, based on the previous discussion, and due to the comparatively little experience in Latin America with these issues, the suggested target value to be met in the MRS by 2030 is 50% of the total mixed waste collected, before landfilling.

5.1.3 Greenhouse gases (GHG) associated to MSW management

Since the beginning of the nineties, climate change has directed attention to improve solid waste management practices. Data show that MSW management and wastewater contribute to approximately three percent of current global anthropogenic GHG emissions (UN Habitat 2004). GHG can be used as indicators to evaluate environmental effects of different waste management practices.

Direct GHG emissions, associated to waste management activities correspond to emissions from landfill sites, incineration plants, recycling operations and collection of residues. On the other hand, emissions associated with the production of materials that can be potentially replaced by substitution of secondary raw materials are usually accounted as avoided emissions. Additionally, emissions associated with the production of electricity, and/or heat, from burning primary fossil fuels can also be avoided, by combustion of biogas, MSW, or refused derived fuels (RDF).

The total and specific amount of GHG produced in 2007 in the landfills of Santiago de Chile are calculated as explained in Section 3.2.2.3.1, with Equations (17) to (21). Current emissions to the atmosphere are lower, because at present, in two of the landfills of Santiago de Chile, the gas is collected and flared. This amount corresponds to GHG avoided in Table 5.2. Following data is used for the derivation of GHG emissions at landfill sites:

- Waste deposited in landfills between 2001 and 2007.
- The emissions considered correspond to those emitted in 2007, by the decomposition of MSW deposited until that year.
- Share of methane in landfill gas: 55%.
- Landfill gas collection efficiency: 26% (Wens 2008).
- Population of the MRS (2007): 6,676,745 inhabitants (INEc).

Calculations were performed for the total annual gas production, and they are shown in Annex D.

Emissions related with recycling processes (generated and avoided) are calculated as described in Section 3.2.2.3.6. GHG emissions are generated by reprocessing materials in order to make them usable as substitute for conventional materials. Avoided emissions are the result of displacing virgin materials in recycling processes. Materials recycled in 2007 are taken into account.

Emissions related with composting are calculated as described in Section 3.2.2.3.2, for open composting. Generated emissions correspond to those arising directly from the composting process. In Santiago de Chile, the compost produced in biological treatment plants is not used to substitute fertilizers, hence avoided emissions from this practice are not considered. Materials composted in 2007 are taken into account. Table 5.2 shows the results of these estimations.

Table 5.2 **Greenhouse gases associated to MSW management – 2007**

MSW management facilities	Landfills	Recycling	Composting	Total
GHG generated [10^3 ton $CO_{2\text{-eq}}$]	2,000	58	0.6	2,700
[kg CO_{2eq}/ (person·year)]	295	9	0.1	304
GHG avoided [10^3 ton $CO_{2\text{-eq}}$]	-500	-563	-	-1,000
[kg $CO_{2\text{-eq}}$/ (person·year)]	-77	-84		-161
Net GHG [10^3 ton $CO_{2\text{-eq}}$]	1,500	-500	600	1,600
[kg $CO_{2\text{-eq}}$/ (person·year)]	218	-75	0.1	143

The most critical greenhouse gas related to MSW management in Santiago de Chile is methane, produced in the course of anaerobic biodegradation of waste disposed in landfills. The main reason being the large amount of MSW deposited in landfills. In Chile, (i.e. Santiago de Chile) there is lack of regulations to reduce the disposal of untreated waste in landfills. Additionally, the landfill gas generated is currently only collected and flared in two of the landfill sites of the MRS. In this regards, there are also some technical limitations, because even if the infrastructure for capture of landfill gas is provided, it is not possible to capture it with 100% efficiency, and the inadequacy of landfills covers should also be considered.

GHG have an effect on climate change, having consequently an impact on ecosystems and human health. Sustainability rules that are at risks, caused by the current quantities of greenhouse gas emissions are the *regeneration capacity of natural systems* and the *minimization of adverse health impacts caused by the environment*.

The collection and flaring of landfill gas is one method to reduce these emissions and their impacts. However, upstream measures are also required, such as waste reduction, reuse, recycling, including biological treatment. The capturing and flaring of landfill gas is financed by Clean Development Mechanisms (CDM) projects, resulting in some instances in an extra income for companies operating the landfills in Santiago de Chile (Loma los Colorados and Santa Marta landfills).

In Germany, for example GHG emissions associated to waste management amounted to 50 kg CO_{2eq}/(person·year) in 1990. Thanks to the reduction in the amount of MSW stored in landfills, together with upgrading of technical issues such as landfill covers, and collection of landfill gas, this value was reduced to 13 kg CO_{2eq}/(person·year) in 2005 (Butz 2009). Moreover with the implementation of the Ordinance on Environmentally Compatible Storage of Waste from Human Settlements and on Biological Waste-Treatment Facilities (*Abfallablagerungsverordnung - AbfAblV*) in 2005, this value has been further reduced.

It should be noted, that Chile is as a non Annex I country of the Kyoto Protocol, therefore it does not have the obligation to reduce its GHG emissions. However, there is an economic incentive for the implementation of these projects because they represent additional income for landfills' operators. Furthermore, in Chile there is a National Action Plan of Climate Change which provides the framework for impacts' evaluation, vulnerability and adaptation to climate change, in addition to GHG mitigation in the country (CONAMA 2008).

Due the fact that currently, collecting and flaring of landfill gas is taking place in Santiago de Chile and that according to (Bräutigam et al. 2009) the separate collection and composting of 50% of garden and food waste presents the potential to reduce landfill gas emissions by about 30% in the MRS, a reduction of 50% of the total emissions is suggested as target value for 2030, corresponding to a value of 71.5 kg CO_{2eq}/(person·year).

5.1.4 Waste fraction recovered as material or energy

A relevant precondition for sustainable development is the resources use rate, closing the loop of materials utilization, which starts by extracting natural resources, and follows with processing, manufacturing, distribution and final consumption. Saving resources is one of the main benefits of recycling, and at the same time it can have economic benefits if costs are lower than savings. Current estimates of the world secondary material markets size account to 600 million tons. The Bureau of International Recycling estimates that the recycling industry generates about US$160 billion (Lacoste and Chalmin 2006). These figures show that recycling is an ecological and an economic issue as well (Chalmin and Lacoste 2006).

Composting is practiced since several years in rural areas to convert biowaste into manure, which can be used as fertilizer. In Austria, for example, 40% of the produced waste is composted (Vehlow 2008b), however, in order to obtain high quality compost, separation of the biogenic fraction at the household level is usually required. International experience shows that this is generally more feasible in rural areas.

Energy recovery is another way for the conservation of resources. The energy contented in MSW can be recovered by using the biogas generated, in anaerobic digestion processes, by using the heat released in thermal inertization processes, or by co-processing alternative derived fuels in power plants, cements kilns, etc. Heat and electric power recovered from the biogenic fraction of waste can replace the respective amount of energy produced by fossil fuels. This represents an additional benefit, because the CO_2 emitted by combustion of this fraction does not contribute to climate change (IPCC 2007, VDI 3460).

In Figure 5.1, data about secondary raw materials in Santiago de Chile is depicted. The dotted bars represent the total material flow in the MSW streams for the year 2007. Availability of paper in the solid waste of the MRS ($600 \cdot 10^3$ Mg/year) is theoretically enough to cover the industry requirements for packaging paper production in the Region ($500 \cdot 10^3$ Mg/year), however only $200 \cdot 10^3$ Mg/year of paper are currently being recycled in Santiago de Chile. In contrast, availability of glass in the MSW flow ($100 \cdot 10^3$ Mg/year) is not enough to cover the industrial secondary raw material requirements ($420 \cdot 10^3$ Mg/year). This difference could be attributed to the fact, that in 2007 Chile exported 350 million liter of wine bottles (CCV undated), thus glass produced in the country does not enter its solid waste material flow. Nevertheless, the total potential is not being used, since the recycling rate of glass is about 16%. On the contrary, for scrap nearly the whole flow potential is being used, attributable to the close cooperation between Gerdau Aza and primary informal collectors. The case of plastic is more difficult to analyze, because of the large diversity of plastic types present in MSW flows, and to the fact that mostly PET bottles are recycled in Chile.

With a recycling rate of 14%, recycling in the MRS is well placed compared with other Latin American countries, whose recycling rate average in 2005 was approximately 2.2% (PAHO 2005), albeit recycling potential in Santiago de Chile has not been fully exhausted (Figure 5.1).

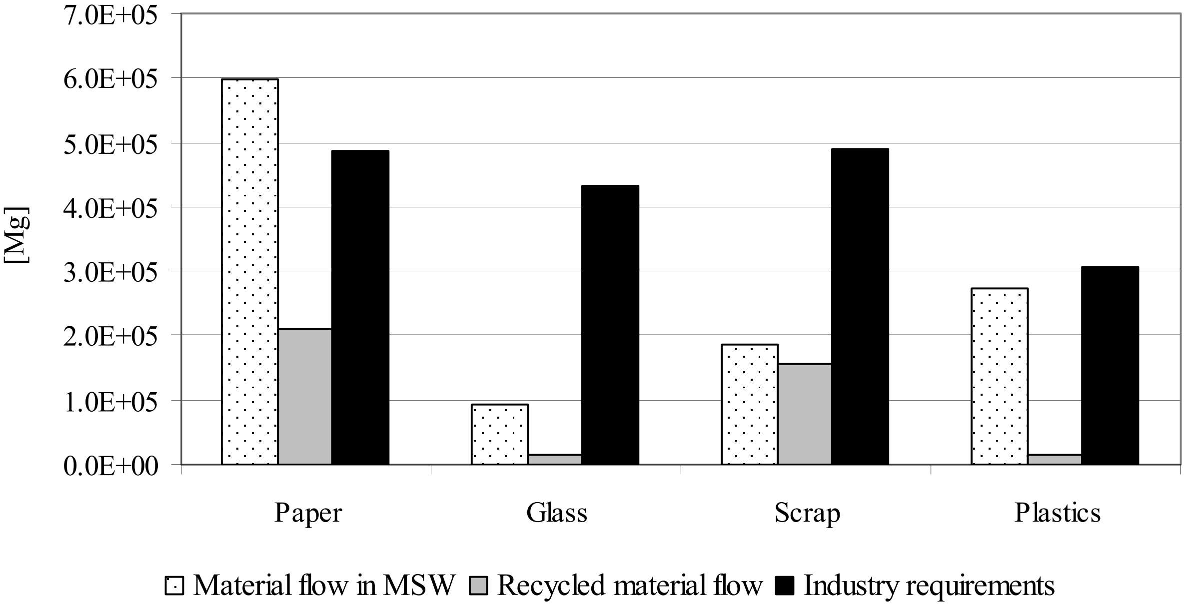

Figure 5.1 Comparison of secondary materials requirements and availability

Moreover, the total recycling rate is only achieved thanks to the participation of the informal sector, because formal recycling is less than one percent. Composting is used to treat less than one percent of the biowaste generated, and the energy content of the MSW is not recovered[12].

In Chile, there is lack of laws and binding regulations in the waste management in general, and recycling in particular. Furthermore, there is lack of infrastructure encouraging voluntary recycling actions. Environmental awareness and source segregation campaigns have been limited to less than 10% of the total municipalities of the MRS. As mentioned above, low costs of landfilling make it difficult to implement other waste treatment technologies, aiming to pretreat MSW and aiming to recover materials and energy.

Low recycling and energy recovery from solid waste may lead to depletion of natural resources and reduced life time of landfills. This turns out in land consumption, as well as in costs associated with construction of new landfill sites. Furthermore, processing virgin material consumes considerable quantities of energy. Production by using secondary raw materials reduces energy requirements in several manufacturing processes. On the other hand, generation of electricity from fossil fuels produces CO_2 emissions. Energy recovered from the biogenic fraction of MSW would avoid the release of those emissions.

Negative impacts of low recycling rates poses a threat towards the *sparing use of non renewable resources*, the *regeneration capacity of natural systems* and the *guaranty of justice in waste management.*

Increasing the recovery of materials and energy from solid waste reduces the negative environmental impacts, caused by waste throughout its life-span, besides waste becomes a potential resource to be exploited. A recycling strategy for the MRS was developed at the regional level by CONAMA (CONAMA 2005a), the goal of which was to obtain a recycling rate of 20% in 2006, value that has not been reached so far. In 2009, a new target was set at 25%, to be fulfilled by 2020. This value according to the Chartered Institution of Waste Management corresponds to a high recycling rate.

Regarding energy recovery from MSW, in 2008 the General Law of Electric Services of Chile was modified, in order to promote the use of non conventional renewable energy sources.

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[12] At the end of 2009, one of the landfills in MRS started to generate electricity from landfill gas

With this modification, those enterprises supplying more than 200 MW should substitute 5% of their energy supply with renewable energy, between 2010 and 2014. From 2014 an annual increase of 0.5% should take place to reach 10% in 2024 (BCN 2008). The use of the biodegradable fraction of MSW (non fossil combustible), presents a potential to contribute to meet these targets in the MRS.

Public interest in recycling has increased significantly over the last years worldwide. MSW recycling is already practiced successfully in numerous countries. In the Unites States, for instance, the recycling rate in 2008 was 33%, including composting (US EPA 2009) and in Berlin for the year 2008, material and energetic recovery amounted to 40% and 47% respectively (BSGUV undated). Countries having an advanced MSW management count with infrastructure to reduce reliance on landfills, have relevant policy, planning and adequate financing mechanisms. In the European Union for example there is an established strategy on prevention, recycling and diversion of waste from landfills.

It is suggested, that in Santiago de Chile, recovery targets not only address the recovery of recyclable materials, but also the food and yard waste fractions, because it corresponds to almost 50% of the total MSW of Santiago de Chile. As illustrated in the case of La Pintana in Section 4.4.3.1.1, collecting and processing biowaste significantly increase recovery rates. Additionally, the informal sector should be involved in the solid waste recycling system, because currently 90% of MSW recycled flows are collected and sorted by this group.

Consequently, based on political targets already set for recycling and potential possibilities of energy recovery from waste in Chile, a total recovery of 36%, including composting and energetic recovery is suggested for 2030.

5.1.5 Remaining lifetime of adequate waste treatment and disposal facilities

Safe waste disposal represents an important pre-requisite of sustainability in waste management, especially in regards of fairness at the intra and inter generational level. Unsafe disposal poses several risks to humans, which is one of the constitutive elements of sustainability according to the Integrative Sustainability Concept, and to the environment, by polluting soils, water bodies and contributing to climate change. Additionally, this indicator can be used as a measure of the conservation of natural resources in the MRS.

As mentioned above, MSW management in Santiago de Chile has focused on improving collection and final disposal sites. Currently about 86% of waste generated is deposited in one of the three landfills located in the area. According to the Environmental Impact Assessment of the landfills located in Santiago de Chile, the lifetime expectancy of two of them will be reached in 2022 and the other one in 2045. However, the lifetime of a landfill depends on the size of the facility, the disposal and compaction rate, and thus it differs from design capacities.

The steady increase of waste and the limited capacity of each landfill, give reason about the importance to gain information on the quantity of waste hitherto disposed of in the landfills and on their remaining lifespan. This helps to plan for a new landfill or for expansion of an existing landfill in due course. Any solid waste management plan should be elaborated for a long perspective, considering changes in waste generation and composition. Additionally, extended lifetime of landfills constitute money savings related with less land requirements and avoidance of construction of new sites.

At the moment, the capacity of the existing landfills has been used up to nearly 11%, hence it does not have any immediate negative impact. However, it is an indicator to have under constant monitoring in order to avoid problems such as those taking place in Naples, Italy in 2007, when rotting waste was pilled up in the streets of the city, because the region had run out of landfills (Smoltczyk 2008, Writers 2008).

Construction of new disposal sites should be planned in due course, in order to assure proper collection and transport of the MSW produced, and to avoid associated problems to human health and the environment. The remaining lifetime of landfills should be at least of 10 years, which is approximately the time that it takes for sitting, licensing procedures and construction of new sites (UNEP 2005).

5.1.6 Coverage degree for the MSW management costs

One of the most important ways to improve solid waste management is to improve its municipal finance system. An economic problem associated with MSW management in low and middle income countries is given by a disparity between income and expenditure. In several cases, this is caused by underestimation of management services and by evasion or even lack of garbage fees. In large cities, such as the Metropolitan Region of Santiago, characterized by rapid population growth, an by a rise in waste generation and associated solid waste services, it is expected that these costs increase further, in addition to the necessity to find appropriate financial solutions.

As explained in Section 4.5, the level of costs recovery in the MRS is 51%. Clearly, this situation produces inequity. One of the causes of the low waste management costs recovery is the large fraction of the premises that are not included in the payment of waste management services. Moreover, the municipalities must pay the cost differences, generating public debts, and citizens do not feel responsible for the waste they produce. On the contrary, in communities with a large proportion of expensive properties, the municipality is able to recover the costs of MSW management without significant efforts.

Another negative effect of a low costs recovery is the difficulty to pay externalities associated with waste management. These externalities include contamination of surface and groundwater bodies, or costs of long term care of landfills. Inclusion of negative externalities in the calculation of waste tariffs may favor the implementation of alternative treatments for the waste generated.

The sustainability rules that are at risk in this case are the *organization of the waste management system to justifiable overall economic costs for a fairer development* and the *minimization of adverse health impacts caused by the environment*.

A successful solid waste management system requires financial autonomy and accountability, by adequate service fees, access to direct funds allocated to waste management and understanding of current costs. According to the *polluter pays' principle* waste producers should cover the total costs for management and treatment of the waste they generate. However, it is argued (Van der Klundert 1999) that often tariffs based on real costs are not affordable for the lower income groups; hence an alternative solution is the financing of these costs by every stakeholder getting a benefit from these services. To achieve this aim, the total costs, including operation, maintenance, and investments should be analyzed before fees are set, breaking down all the costs. The garbage fees should adapt, at the same time, to local willingness to pay. Additionally, ability to pay and payment structures can be designed to reflect different levels of affordability, i.e. the more wealthy users subsidize the poorest.

In Chile, some actions have been taken for this purpose. The Integrated Waste Management National Politic (2005) established short and middle term goals to improve the financing of the total waste management system. Consequently, a target value of 100% is suggested for 2030, in a way where the waste charges are introduced and then rise progressively over time, distinguishing among costs for residential, commercial and industrial waste, and by improving the system of waste fees collection, in order to ensure its applicability at the political, institutional and social level.

5.1.7 Fraction of gross domestic product spent on municipal solid waste management

Investments in MSW management services should be affordable for a region. Similar levels of investment in countries with disparate economic histories, implies that less developed countries invest a much larger fraction of their GDP in MSW management.

The selected indicator to measure the affordability of a particular waste management strategy in a region corresponds to the fraction of GDP spent on municipal solid waste management. This indicator reflects which budget fraction a region is able to spend on MSW management.

Table 5.3 shows the MSW management costs for cities with large variation in their gross domestic products and waste management systems. It is clear, that each country should establish its MSW management priorities; the measures and technologies suggested as well as economic resources to be allocated in a sustainable waste management, should therefore take the limiting economic factor into consideration

Table 5.3 Comparison of MSW management costs in different cities (Brunner and Fellner 2007)

		Santiago de Chile	Vienna	Damascus	Dhaka City
GDP	**[US$/(person·year)]**	10,500	27,300	1,360	370
Cost/GDP	**[%]**	0.22	0.40	0.28	0.18
Costs	**[US$/(person·year)]**	17	106	3.8	0.7

The rise of the GDP of Santiago de Chile brought about an increase in the generation of MSW (Figure 4.2). Nevertheless, the costs per ton of waste have remained nearly constant for the same period (Figure 5.2). On the other hand, a steady increase in the total expenditures on MSW management occurred between 2001 and 2007, which is attributed to the increase of MSW flows (Figure 5.3). However, the fraction of the GDP spent on MSW management has decreased for the same period, as depicted in Figure 5.2. The constant value of $Cost/MSW$, together with the decrease of $Cost/GDP$ suggest on the first place, that the GDP increase in the Region has been larger than the MSW generation increase. On the second place, this suggests that even though there was a rise on the GDP of Chile (i.e. MRS) during the last years, the expenditures on MSW management have not proportionally increased.

In the light of the economic development of Chile, a larger financial capacity to afford the construction and operation of MSW management facilities is expected. Additionally, the inclusion of external costs[13] of environmental, ecological and social impacts should also be included in the costs calculations. A low expenditure on waste management may generate *adverse health impacts caused by the environment* and put into jeopardy the *regeneration capacity of natural systems*.

On the whole, the fraction of GDP spent on MSW management lies between 0.2 and 0.5% (Brunner and Fellner 2007, Lederer 2008). An increase in the current value, until 0.3% in 2030 is therefore suggested for Santiago de Chile.

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[13] Externalities include collection and treatment of landfill emissions, not only during operation, but also after closure, re-vegetation, etc.

5.1.8 Income level of primary collectors in relation to household income in Santiago de Chile

A further sustainability requirement is that all members of society should be in a position to secure their livelihood, with work that they have chosen. This requirement depends on jobs and income situation.

In the specific case of waste management in the MRS, the informal primary waste collectors emerge as a vulnerable group. The correlation between their income level and the average individual household income is used to operationalize the sustainability goal of ensuring an independent livelihood.

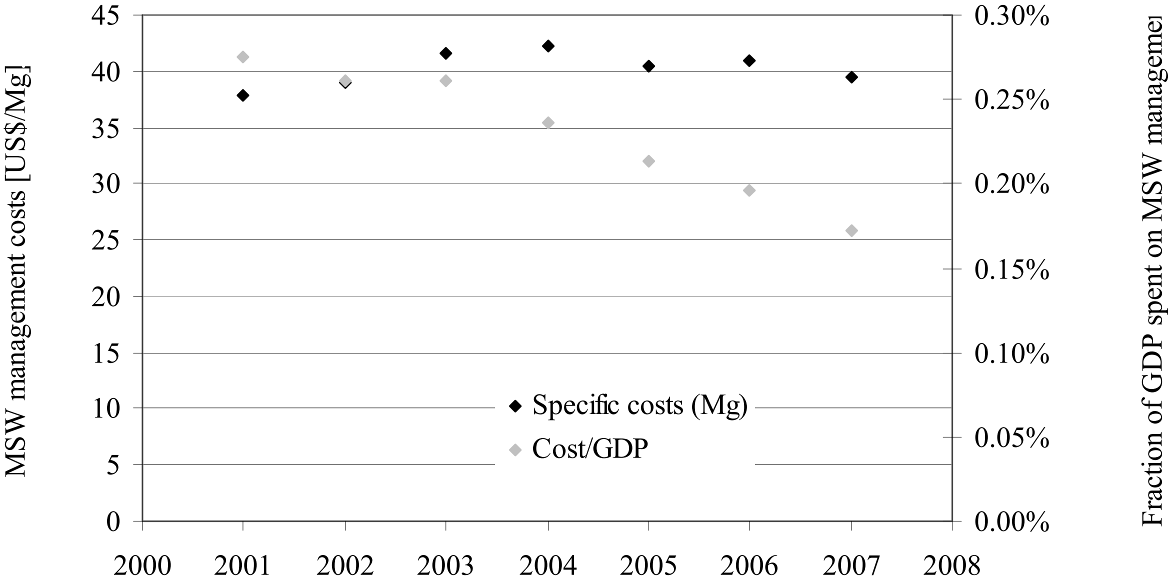

Figure 5.2 MSW management costs and fraction of GDP spent on MSW management (based on SINIM undated, IMF undated, CONAMA 2009)

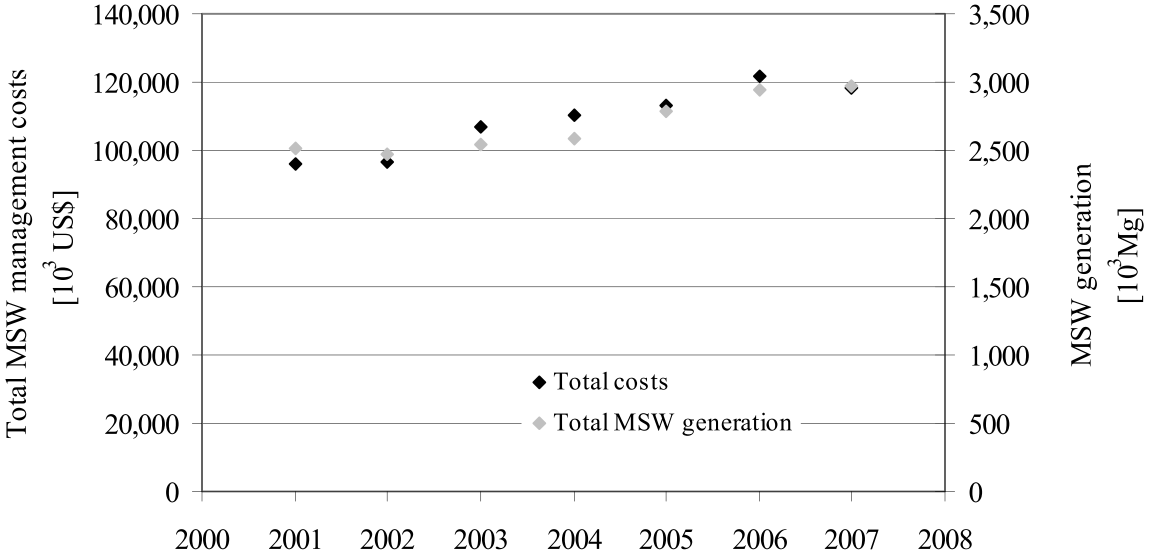

Figure 5.3 Evolution of MSW generation and MSW management costs (SINIM undated, IMF undated)

The earnings of informal primary collectors are difficult to determine. First of all, there are variations in the price of materials, as well as in the amount collected. Working hours, collection areas, tools and collection capacity vary widely. There are collectors who are able to earn a larger income than the minimum wage; there are others who are satisfied by obtaining some money for their daily survival (Casa de la Paz 2007b).

Currently, the average household income of Santiago de Chile is US$1,440 per month (740,000 Chilean Pesos) (Mideplan 2007) with a household size of 3.6, the income per person is approximately US$400 per month.

A recent survey carried out to 3% of the informal collectors working in the MRS showed that roughly 22% of the informal workers have a monthly income larger than the individual household income. The largest fraction of primary collectors (44%) is located in the cluster earning between 49% and 97% of an individual household, as Table 5.4 shows.

Table 5.4 Income of informal primary collectors in the MRS, 2010 (based on Valenzuela et al. 2010)

Informal collectors [%] *	Monthly income [US$]	Income in relation to individual household income [%]
28	< 190	0 – 48
44	191 – 385	49 – 97
17	386 – 580	98 – 145
5	>580	> 146

* The remaining 6% did not answer this question

Table 5.5 shows average values of materials collected and their prices in 2009. It should be noted, that these prices refer to the buying price offered by production companies. Middlemen usually buy materials from primary collectors at a lower price. Additionally, not all the waste pickers collect at the same time the wide diversity of materials. For example collectors of paper and cardboard could earn around US$ 120 per month, and metals collectors around US$ 250 per month. Sometimes waste pickers earn a larger income by collecting plastic and glass bottles as well.

Table 5.5 Earnings of informal workers in the MRS (Casa de la Paz 2007a, 2007b, Sorepa, Recupac)

Materials	Daily amount collected [kg/day]	Price paid by industries [US$/Mg]	Income [US$/month]
Paper	54		
Newspaper	20%	66	17
Magazines	20%	76	20
Cardboard	40%	74	38
White	20%	160	41
Plastics	4	760	7
Metals	42		
Ferrous metals	80%	100	81
Aluminum	8%	900	73
Copper	2%	4,000	81
Iron	10%	120	12

At the moment of the field research, the waste authorities did not acknowledge the work carried out by the waste pickers, and in some cases there was also lack of acceptance from the civil society. The informal collectors are in daily contact with residues, which may be associated with dirt and diseases.

By having low and instable income, it is difficult for the primary collectors to have the chance to secure their own subsistence. Low incomes might discourage these workers, decreasing their working efficiency, and therefore the amount of materials collected and recycled. Informal collectors tend to occupy the base of the recycling hierarchy and this reduces their potential income, which depends on the prices the wholesalers are willing to pay for the materials.

Several sustainability rules are threaten in regards of the income of the informal primary collectors, for instance, the *sparing use of non renewable resources*, the *minimization of adverse health impacts caused by the environme*nt, the *development of human and knowledge capital* and the *guaranty of the possibility of independent existence, which fulfills the basic needs and creates development opportunities.*

According to different studies (Chapter 6), there are several experiences on formation of scavengers' cooperatives. These cooperatives have helped those concerned to improve their living conditions, improving their working efficiency, and quality of materials, consequently giving them access to better incomes. In Colombia, for example, scavenger cooperatives have formed regional marketing associations, which allow them to accumulate and sell recyclables in important volumes, obtaining higher prices than if they would work individually. Cooperative members report a higher standard of living, as well as improvements in self-esteem and self-reliance compared to an independent work (Medina 1997).

The target value for the income of primary collectors is set in 100% of the average individual household income. It is assumed, that this value is sufficient to guarantee basic needs, improve living standards and reduce poverty.

5.2 Summary of Sustainability Assessment and Identified Causes

Solid waste management is a significant and complex task, and as described in the previous Section the current MSW management in Santiago de Chile present potential problems which threaten several of the minimum requirements of sustainability (Table 5.6). If these negative impacts are irreversible, affect a large number of people, and have long term duration, they pose a threat to the achievement of sustainable development (Büscher undated).

5.2.1 Irreversibility of impacts

It is a fact that landfills exert an impact on the environment, in particular referring to land use, aesthetics, wildlife and habitats (Kranert et al. 2010). Even though, it is possible to revegetate landfills, the process is complex and can only be completed long after its closure. Additionally, exposure to certain chemicals which could leach from garbage, e.g. cyanides, mercury and polychlorinated biphenyls are highly toxic and if released untreated can lead to chronic disease, cancer, infections or death, affecting irreversible the health of the population. Contamination of groundwater is extremely complex to reverse and it has been estimated that it may be a risk even after several centuries, contaminating nearby water bodies, which will remain unusable for several generations (Ludwig et al. 2003). In addition, impacts of explosions and fires in storage sites and landfills may be irreversible, if it affects people and capital welfare.

Moreover, climate change caused by increase of GHG emissions is irreversible for a long time, even after emissions stop (Solomon et al. 2008). On the other hand, the extraction of non renewable resources is irreversible, but can be avoided if MSW is recovered as material or energy.

5.2.2 Spatial range

Land consumption, as a consequence of landfill construction, is a regional problem. Additionally, groundwater contamination caused by leachates from landfills is a regional problem that may affect a large section of the population living in the MRS. Furthermore, explosions and fires in landfills and storage sites have an impact in the nearby area, affecting people working and living close to the facilities. On the other hand, CH_4 and CO_2 emissions impact the global climate, and affect a vast number of people worldwide.

In relation to recycling and extraction of natural resources, most of the resources used in the Metropolitan Region are imported from other regions of Chile, therefore the spatial range of the resources depletion goes beyond the regional level. Additional health impacts of improper waste management are a local as well as a regional problem. Problems caused by public debts in this case are related to municipal debts, being therefore a local issue.

Table 5.6 Sustainability indicators for MSW management in Santiago de Chile (Seidl 2008, Gonzalez et al. 2009)

Indicator	Current value (2007)	Target value (2030)
Specific waste generation [kg/(person·day)]	1.2	Max. 1.6
Amount of mixed waste pretreated to reduce organic carbon content in relation to total mixed waste [%]	0	50
Greenhouse gases emitted during waste management [kg CO_{2eq}/(person·year)]	143	71.5
Waste fraction recovered as material or energy [%]	14	36
Remaining lifetime of adequate waste treatment and disposal facilities [years]	Santa Marta: 12 Santiago Poniente: 12 Loma los Colorados: 35	At least 10 years for each site, after 2030
Coverage degree of costs for the waste management [%]	51	100
Fraction of gross domestic product spent on municipal solid waste management [%]	0.22	0.30
Income level of informal workers in relation with individual household income [%]	76	100

5.2.3 Temporal range

Lifetime of landfills is extended to about 30 years. When capacity is reached, landfills must be covered and they require post closure measures for at least other 30 years. Biological degradation processes, and associated emissions continue after closure, and their risks can last for several centuries. Additionally, the impact of CH_4 and CO_2 emissions on global climate and groundwater contamination is a long term concern. Infections and disease, quality and life expectancy caused by poor solid waste management can be long term. The impact of resources depletion is of long duration. This depletion can be minimized by recycling materials.

Figure 5.4 shows in a comparative way the current value of the indicators and the established sustainability target, by means of the distance to target approach. Each absolute target value has been normalized and transformed to a target value of 100%. A largest distance to this target means a largest distance (i.e. efforts, action plans) to achieve a sustainable development.

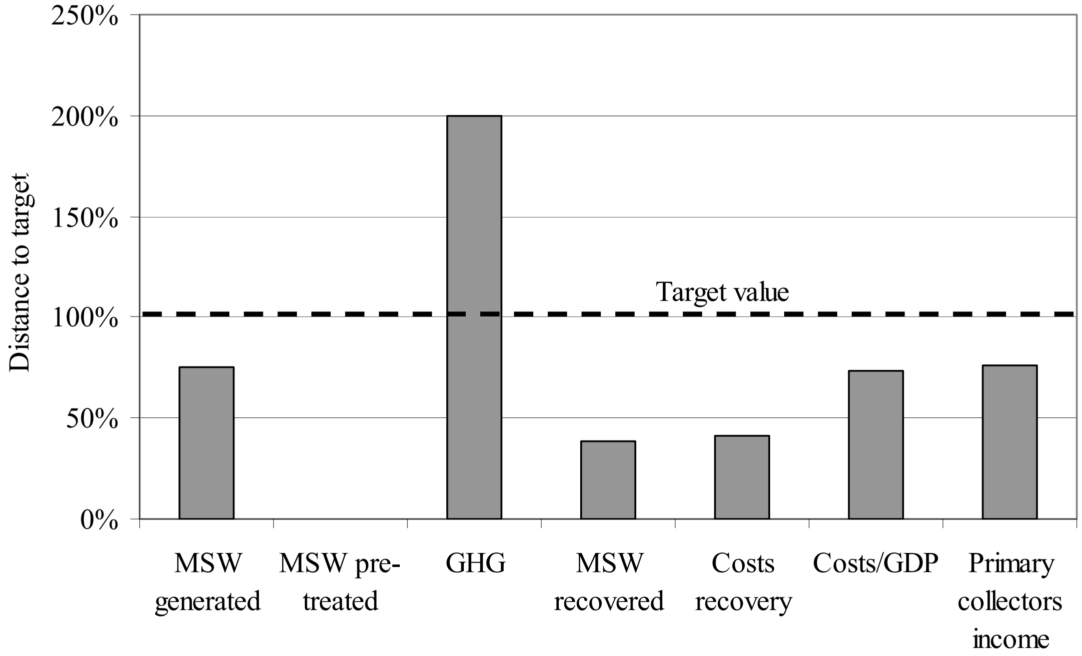

Figure 5.4 Distance to sustainable target of MSW management indicators - 2007 (Seidl 2008, Gonzalez et al. 2009)

The current MSW management system of Santiago de Chile presents significant deficits, which threaten the quality and sustainability of the urban habitat. As observed in Figure 5.4, the most critical issues (largest distance to target) are related to maintain the regeneration capacity of the environment, which is shown by the amount of waste that is pretreated, the quantity of GHG emissions associated with MSW treatment and disposal and the quantity of waste that is recovered as material or energy. Because the associated negative impacts of these indicators are irreversible, have an important spatial and temporal range (Table 5.7), it can be concluded that they constitute the most serious risks for the achievement of sustainable development in the MRS and should be the base to find appropriate and affordable solutions.

Once, deficits of the MSW management system in the MRS are identified, the next step is to investigate which root-causes led to these deficits, hence facilitating to find out improvement measures. The detailed analysis of the MSW management situation, together with interviews carried out to actors with competences in the research field, allowed identifying the most important causes responsible for the sustainability deficits, which can be summarized as:

Governance

- Low inter-municipal coordination.
- Current MSW management projects focus markedly on closure of old dumping sites and improvement of technical standards in landfills rather than in implementation of alternative waste treatments, in order to divert waste from landfills.
- A large fraction of the population is exempted of payment for MSW management services.

Laws and regulations

- Lack of command and control instruments regarding waste prevention and pre-treatment.
- Lack of instruments and policies aiming to incorporate the real costs of MSW management (including post closure of landfills) into established waste tariffs.
- Lack of a national or regional framework for integration of the informal sector.

Table 5.7 Risks associated with MSW management in Santiago de Chile

Problems	Causes	Irreversi-bility	Spatial range	Temporal term	Sustainability guideline affected
Land consumption by landfills	Low pretreatment High waste generation Low waste recovery	x	Regional	Long term	Regeneration capacity of natural systems Safe disposal
Infection/ Chronic diseases	High haste generation Low waste recovery Low costs of MSW in relation to GDP Low income level of primary collectors	x (depending on the kind of disease)	Local	Medium term	Adverse health effects caused by the environment
Climate change	Low pretreatment High waste generation Low waste recovery Low coverage degree of the waste management system's costs Low costs of MSW in relation to GDP	x	Global	Long term	Regeneration capacity of natural systems Adverse health effects caused by the environment
Air pollution	High waste generation Low technical standards	x	Regional, global	Medium term	Regeneration capacity of natural systems Adverse health effects caused by the environment
Water bodies pollution	Low pretreatment High waste generation Low waste recovery Low coverage degree of the waste management system's costs Low costs of MSW in relation to GDP	x	Regional	Long term	Regeneration capacity of natural systems Adverse health effects caused by the environment
Depletion of resources	High waste generation Low waste recovery	x	Regional, global	Long term	Sparing use of resources Maintaining the regeneration capacity of natural systems Justice in waste management
Depletion of fossil fuels	Low waste recovery	x	Regional, global	Long term	Sparing use of resources Regeneration capacity of natural systems Justice in waste management
Explosions/ Fires	Low pretreatment High waste generation Low waste recovery Low coverage degree of the waste management system's costs	x	Local	Short term	Adverse health effects caused by the environment

Continuation Table 5.7 Risks associated with MSW management in Santiago de Chile

Problems	Causes	Irreversi-bility	Spatial range	Temporal term	Sustainability guideline affected
Public debts	Low pretreatment High waste generation Low coverage degree of the waste management system's costs	-	Local	Short to long duration	Justifiable overall economic costs for a fairer development. Minimization of adverse health effects caused by the environment
Non ability to secure own existence, based on own income	Low income level of primary collectors	-	Local	Short to long duration	Adverse health effects caused by the environment Development of human and knowledge capital Possibility of independent existence

Financial

- Low prices of landfilling make economically unfeasible implementation of alternative waste management technologies.
- Non financial equilibrium between income and expenses associated with MSW management costs.

Technical

- Inefficient production processes.
- Inadequate infrastructure to encourage voluntary recycling actions.

Social-economic

- Economic development of Chile, changing consumption patterns.
- Low environmental awareness and education of the citizens in recycling and separation of MSW at the source.
- Lack of recognition of the work carried out by the waste pickers.
- Low awareness of the population about responsibility of payment for waste management services.

These root-causes should be used as basis for the formulation of improvement measures in order to achieve a more sustainable system of waste management in the MRS.

Chapter 6
Informal Waste Sector

A particular characteristic of waste management in low and middle income countries is the presence of an informal sector, working parallel to publicly organized systems. In Latin America, informal waste collectors can be found in almost all middle to large cities (PAHO 2005) and Santiago de Chile is not an exception. Therefore, this Chapter provides information about the current role of the informal sector within the municipal solid waste management in Santiago de Chile. Additionally, the results of the evaluation of how the sector contributes towards sustainable development are given. In the last Section, a review of Latin American experiences where the informal workers formed organizations is provided. These experiences are analyzed at the organizational, political and technical level, in order to find common successful key factors, which could be transferred to the Santiago de Chile case.

6.1 The Informal Waste Sector in the Metropolitan Region of Santiago

Informal waste collection started approximately in the middle of the 20th century in Chile. Of particular importance at that time were the primary collectors[14] of glass bottles, trading glass bottles between householders and the largest glass company of Chile, “Cristalerías Chile” (Pizarro 2005). There were people searching for valuables materials inside trash bins or buying waste at low prices from householders, these materials were then taken to their houses, and were sold to middlemen, a group that also developed depending on the necessities of the industries (Florisbela and Astorga 2006).

Nowadays, primary informal collectors have established sources of recyclable materials, given by specific collection areas or by agreements with large waste producers, such as supermarkets and commercial businesses. The informal collection process starts when the waste pickers take the recyclable materials from their generation point to a stock center, or to their own house, where the materials are classified.

In 2010, a survey carried out to 231 waste pickers, collecting materials in the municipalities of Santiago, Ñuñoa, La Florida, Las Condes, Peñalolén, Quinta Normal, La Pintana and San Joaquín (Valenzuela et al. 2010) showed that 47% of the primary collectors stock materials in their own house; another 32% do not stock the materials at all, selling them daily to middlemen. On one side, this fact brings evidence about the lack of safety associated with the work carried out by these people. On the other side, it shows factors that represent improvement potential, for instance if stock centers were built in strategic areas to decrease the travel time by the waste collectors, between collection points and materials delivery.

Another interesting result of the survey elaborated by (Valenzuela et al. 2010) is that 57% of the waste pickers interviewed collected materials in a different area than where they live (Figure 6.1). Waste pickers working in medium to high income municipalities, such as Santiago, Ñuñoa and Las Condes, arrive from other areas, probably from low income ones. In the case of low income communities (Peñalolén, Quinta Normal and La Pintana), the fraction of people living and coming from other municipalities is more balanced, indicating that waste pickers live mostly in the poorest areas of the MRS. Waste pickers go to richer communities because of the larger quantities of valuable materials found on waste flows. However, the

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[14] The name primary waste collector, informal collector and waste picker are used exchangeable in this thesis. Primary collector refers to the fact that these workers are the first link in the recycling chain.

transfer to richer municipalities also represents longer transportation time for the primary collectors.

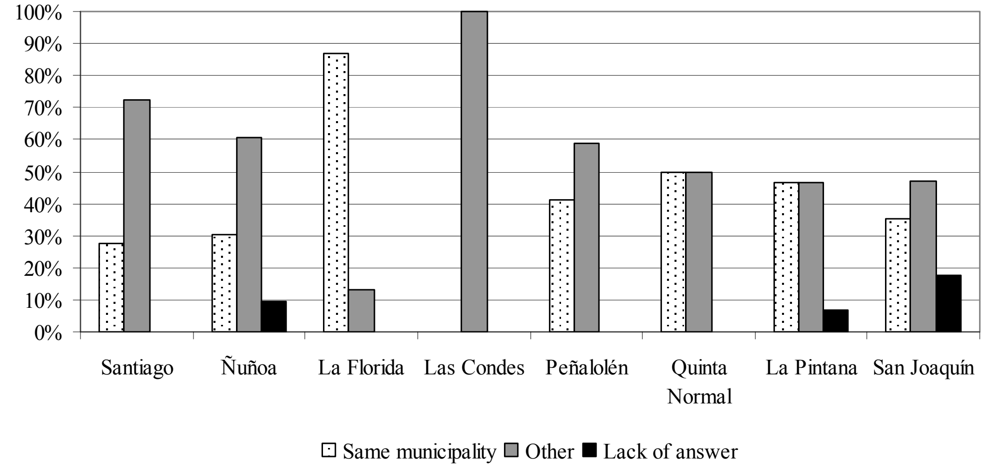


Figure 6.1 Municipalities where waste collectors work (Valenzuela et al. 2010)

As a rule, informal primary collectors work four hours in collection, between two and three hours in materials classification, and they need a transit time of another two hours (Alaniz et al. 1998). The working time of informal workers depends on the schedule of formal collection vehicles, because they search for valuable materials at the collection points before formal collection takes places.

Different alternatives are used to sell the collected and classified materials:

- Middlemen: low volumes of recyclable materials are sold to wholesalers who commercialize them directly to production companies, when they gather required quantities.
- Flea markets: re-usable materials are sold in informal locations or flea markets, usually in the community, where they live. For some waste pickers, this activity corresponds to their main income source.
- Stock centers: these are micro enterprises, managed by waste collectors, with different participation levels. Materials brought by members of the organization and particulars are stored and sold to production companies. Usually, better prices are given to the members of the organization than to particulars.

As mentioned in Section 4.4.3.2, the informal sector plays an important role in the recycling of MSW in Santiago de Chile, with a total contribution to recycling of about 90%. The activities related with the recovery, processing and selling of these materials constitute their main income source.

Organization of the informal waste sector in Santiago de Chile

Regardless of the problems to achieve integration of informal waste workers, there are some examples where the working and living conditions of waste pickers improved, through their organization and training. In these cases, recycling organizations led to the formation of cooperatives and small-scale enterprises.

Organization of informal waste workers in Santiago de Chile backs to the year 1992, when the *First Meeting of "Cartoneros" of Santiago* took place. This meeting was a very important step to start changing the vision towards waste pickers and to regard them as important actors in the waste management (Pizarro 2005). In 1995, the *Second Meeting of "Cartoneros" of Santiago* was hold. More recently, in 2007 and 2008 the *First and Second National Meeting* *of Chilean Recyclers* took place in Maipú and La Serena, respectively. Topics of the meetings included inclusion of collectors in the recycling processes, promotion of association initiatives between them, improvement of their economic activities and strengthening of the Chilean National Movement of Recyclers.

The association that set the basis for the organization of informal collectors in Chile was the Union Association of Independent Collectors (ASRI for its Spanish acronym), which was created in 1997, but has already disappeared. The goal of this organization was to help informal collectors, along Chile, to formalize their work, to provide them with identifications and regulate stock centers. With the formation of ASRI, it was possible that public institutions and NGOs appreciated the work of the waste collectors, contributing with financial resources to acquire working tools and with delivery of stock centers locations (Alaniz et al. 1998). Even though, ASRI does not exist anymore, several leaders of the organizations are still active and have promoted the National Movement of Recyclers of Chile (MNRCH). This group is in charge of the promotion and formalization of waste pickers, associability between recyclers at the regional, national and international level and it encourages the exchange of experiences and collaboration, as an efficient strategy to improve the labor executed by the informal sector (Alaniz 2009).

In the year 2007, the NGO "Casa de la Paz" undertook an explorative work to characterize organization of informal workers in Chile (Casa de la Paz 2007b). During the study, 13 leaders of organizations and 43 primary collectors were interviewed. A total of 14 organizations were identified in Chile, five of them belonging to the MRS. A summary of the most important results of this explorative work are presented next:

- Primary collectors average age: 49 years
- Primary collectors that did not finish primary school: 46%
- Primary collectors belonging to some sort of organization: 36%
- Primary collectors collecting cardboard: 88%
- Primary collectors collecting metal: 75%
- Primary collectors using tricycles: 81%
- Primary collectors stocking materials at their own house: 51%

For the primary collectors interviewed, one key factor which would have improved their working conditions is the organizational and technical support received from the municipality. Without appropriate infrastructure the possibilities to improve their life and working conditions are very limited (Casa de la Paz 2007b).

6.2 Impacts of the Informal Sector on Sustainable Development

In order to assess which effects the informal waste sector has on the sustainability of the waste system, two opposite scenarios are further investigated, and compared with the current situation (Figure 6.2). The first scenario corresponds to an exclusion situation in which it is assumed that the informal primary collectors are not allowed anymore, because of legal reasons, to perform their collection, classification and recycling activities (Figure 6.3). The main assumption in this scenario is that if waste pickers are not allowed to collect recyclable materials, these will be collected and transported by formal collection to landfills.

The second scenario corresponds to an inclusion situation in which public authorities and the civil society work in cooperation with the informal waste collectors, hence improving their working efficiency (Figure 6.4). In this scenario, it is assumed that the total primary collectors working in the MRS are organized, and by this organization their collection efficiency increases by 40%, meaning that instead of collecting 100 kg/(person·day), they will collect 140 kg/(person·day).

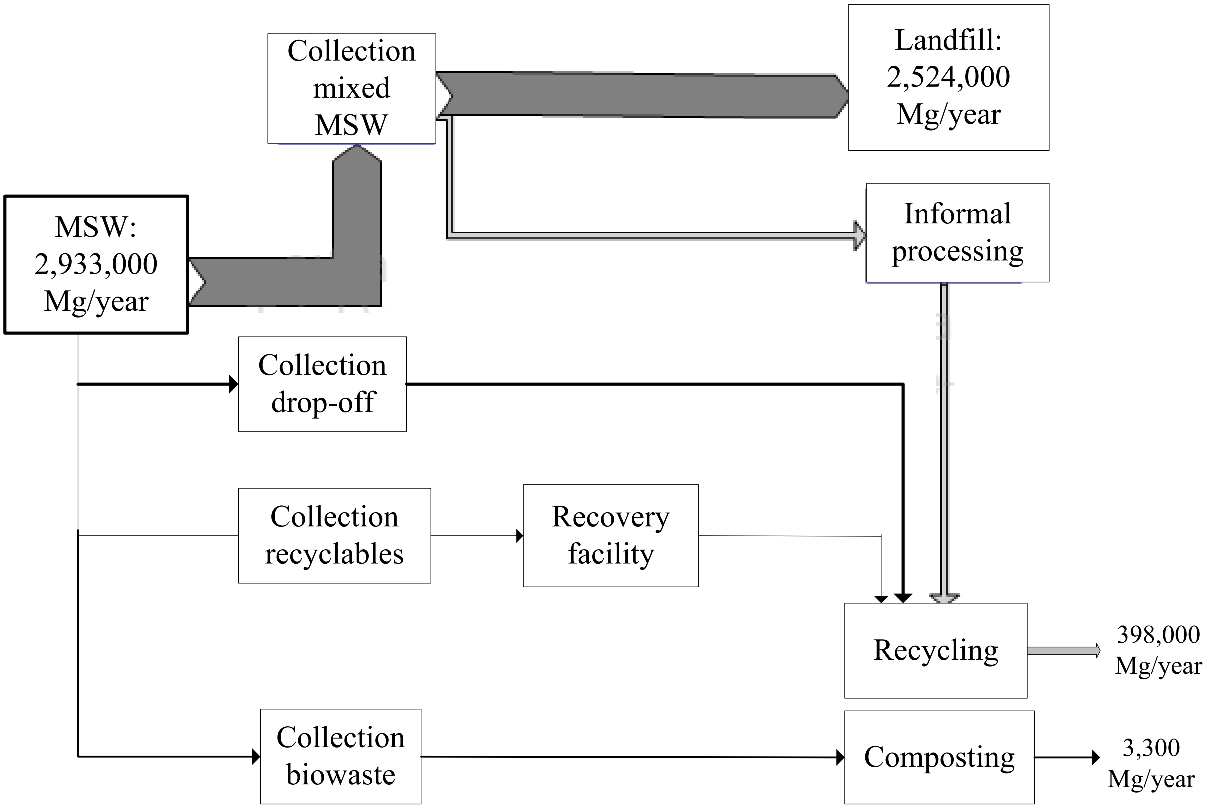


Figure 6.2 **Current MSW management scenario “Sankey” diagram**

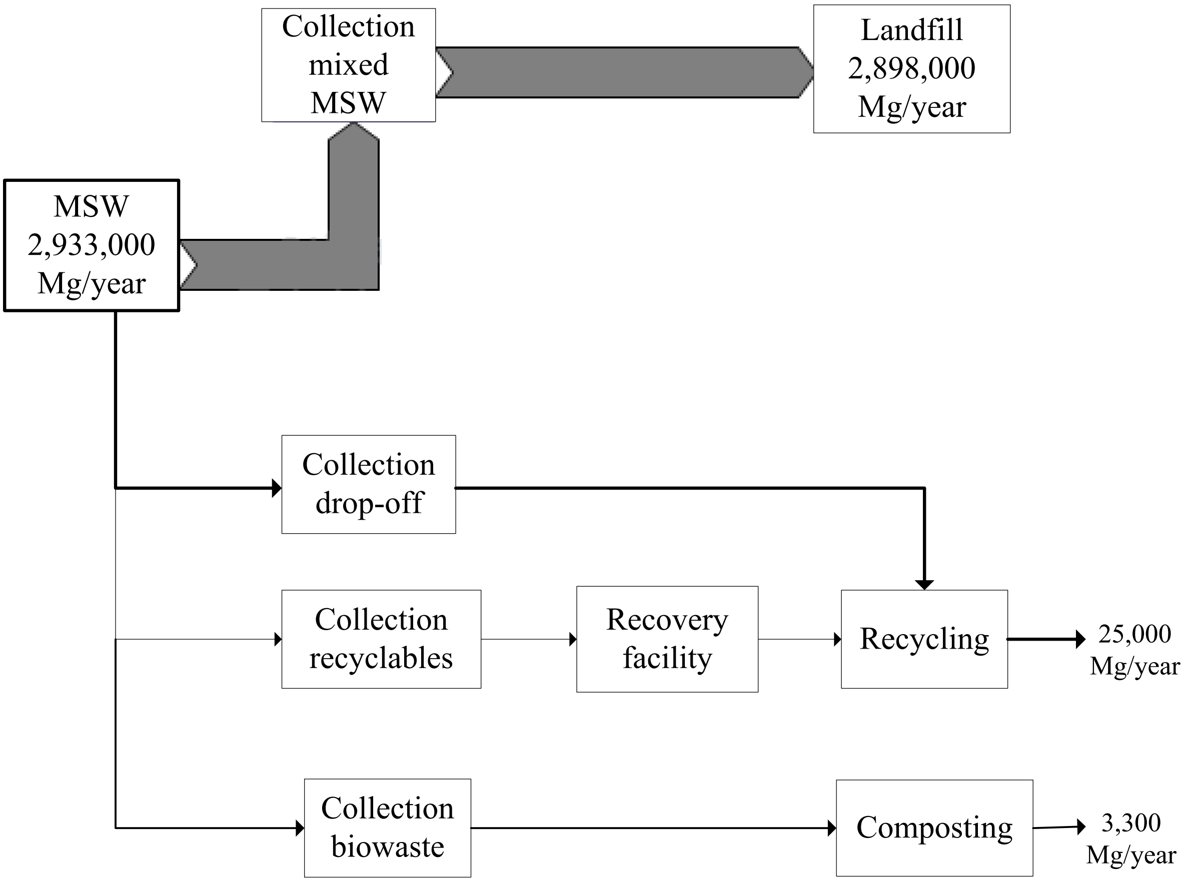


Figure 6.3 **Exclusion of informal sector from current MSW management system “Sankey” diagram**

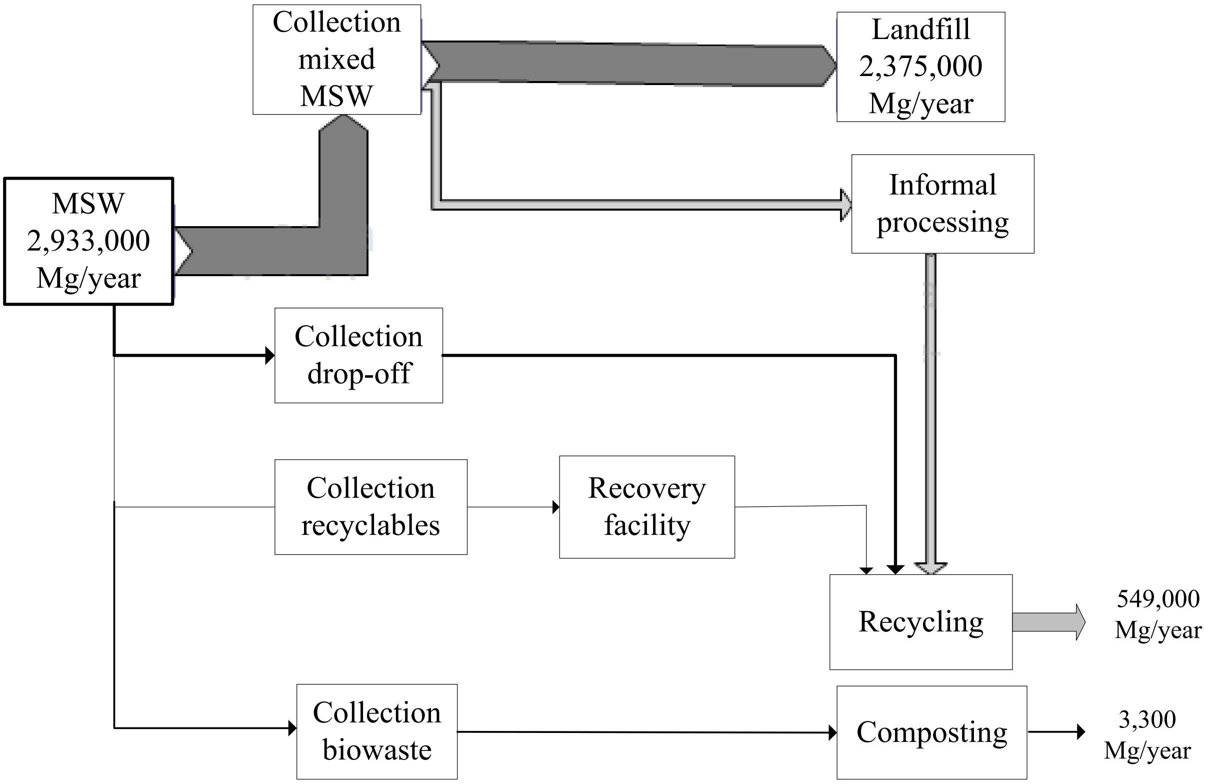


Figure 6.4 **Inclusion of informal sector in current MSW management system "Sankey" diagram**

On the basis of the indicators of sustainability given in Chapter 5, and their comparison with the current MSW management system, the evaluation of these two situations is elaborated. Results are presented in Table 6.1.

6.2.1 Specific waste deposited in landfills

The current flux of MSW landfilled in Santiago de Chile is 1.04 kg/(person·day). In the exclusion case, this amount increases by almost 15%, caused by the important role of the informal sector in collection of recyclable materials. It is assumed, that the MSW which is not collected by the informal workers is formally collected and brought to landfills, and not illegally dumped. Currently, the publicly organized system collecting recyclables is not able to gather the same amount of waste collected by the informal primary collectors.

In contrast, a reduction of almost 7% of waste sent to landfills is achieved in the inclusion case, in comparison with the current value. Based on the analysis of organization experiences of the informal waste sector, it is expected that an inclusion and working cooperation between formal institutions and the informal workers would improve their collection and sorting capacity.

6.2.2 Amount of mixed waste pretreated to reduce organic carbon content in relation to total mixed waste

Changes of exclusion or inclusion of the informal waste sector do not have any effect on this indicator, because the activities of the sector in Santiago de Chile are not regarded as pretreatment.

6.2.3 Greenhouse gases emitted at MSW management facilities

The current quantity of GHG emissions associated with management of MSW is 143 kg/(person·day). An exclusion of informal workers from the system brings about an increase of this value by 55%.

Table 6.1 Effects of exclusion and inclusion of the informal waste sector on sustainability

Indicator	Current situation	Exclusion	Inclusion
Specific waste deposited in landfills* [kg/(person·day)]	1.04	1.19	0.97
Amount of mixed waste pretreated to reduce organic carbon content, in relation to total mixed waste [%]	0	0	0
Greenhouse gases emitted at MSW management facilities [kg CO_{2eq} /(person·year)]	143	222	111
Waste fraction recovered as material or energy [%]	14	1.2	19.1
Coverage degree of costs for the waste management [%]	51	45	55
Fraction of gross domestic product spent on municipal solid waste management [%]	0.20	0.23	0.19
Income level of primary collectors in relation to household income [%]	76	0	107
Remaining life time of adequate waste treatment and disposal facilities [years]		- 2.1	2.4

* the MSW generated is expressed in this case as MSW deposited in landfills

This increase is primarily attributed to emissions associated with recycling of secondary raw materials (Table 6.2). In the exclusion scenario, the total quantity of materials recycled decreases, and hence there is not an emissions reduction associated to recycling processes. Calculations of landfill gas emissions do not show significant variations (Table 6.2), in comparison with the current case. The increase in the landfill gas emissions are attributed to larger fraction of paper and cardboard flows sent to landfills, but these emissions are low compared with emissions associated to decomposition of food waste, which are not affected by an exclusion or inclusion of the informal workers.

Table 6.2 Comparison of GHG emissions, current situation and exclusion, inclusion cases

	Emissions associated with recycling [10^3 Ton CO_{2eq}/year]	Emissions from landfills [10^3 Ton CO_{2eq}/year]
Current	-505	1,458
Exclusion	-15	1,496
Inclusion	-701	1,443

On the other hand, the inclusion situation shows an improvement of 22% in the specific GHG emissions compared to the current scenario. The reduction of GHG emissions achieved is attributed to larger quantities of waste collected and recycled. Substitution of raw materials in manufacturing processes avoids GHG emissions associated to extraction of raw materials. Additionally, the use of secondary raw materials in production processes turns out in energy savings and hence in smaller quantities of GHG, from combustion of fossil fuels.

6.2.4 Waste fraction recovered as material or energy

The current recovery rate in the MRS is roughly 14%. A subtraction of the informal workers from the MSW management system reduces the amount of MSW recovered, by 91%. If the informal waste sector is eliminated, the current publicly organized system does not provide enough infrastructures to collect the vast amount of materials gathered by the informal group.

In contrast, the insertion of the informal waste workers into the system improves the recovering rate by 36%. This increase is attributed to collection of larger quantities of paper, cardboard and metals, achieved by ameliorate collection routes, better working conditions and larger cooperation and acceptance from civil society.

These results demonstrate the essential role that the primary collectors play on current recycling rates. On the other hand, they also indicate that the informal sector is not enough to achieve targets of recovery, which where established in 36% of the total MSW generated (referring to target values given in Chapter 5).

6.2.5 Coverage degree of costs for the waste management

If the informal sector is excluded from the waste management system, more residues have to be collected and deposited in landfills, increasing the total waste management costs. Considering, that income revenue sources do not change, the degree of costs recovering drops by 12%. The monetary deficit created is to be paid by the municipalities, increasing even more the imbalance between revenues and expenditures.

On the contrary, if the informal primary collectors are able to gather more materials, the total costs of formal collection and final disposal decreases, and assuming that revenue sources remain constant, then the degree of costs recovery increases by 8%.

6.2.6 Fraction of gross domestic product spent on municipal solid waste management

The fraction of GDP spent on MSW increases by 15% in the exclusion scenario in comparison with the current value. This change is associated with a raise in transport and disposal costs, because more materials need to be collected by the formal system and need to be transported to sanitary landfills. Even though, a rise in the MSW management costs in relation to the GDP is desirable, this increase should occur in order to achieve improvements in the waste management field, such as upgrading of technical standards in sanitary landfills, construction of new treatment facilities, etc. In this case, however, the rise in costs takes place only because there is an increase in the quantity of waste formally collected and disposed of in landfills.

Alternatively, an inclusion of the informal sector reduces the total costs of MSW, and therefore its share of GDP. This reduction is associated with decreases in the amount of residues collected, transported and deposited in landfills.

6.2.7 Income level of primary collectors in relation to individual household income

The current average income of informal workers corresponds to 76% of the individual household income in Santiago de Chile. Regarding the exclusion case, it is clear that if the informal primary collectors are not allowed to collect recyclable materials, they will not be able to sell these materials and therefore any income to be received in relation to waste management will be zero. Moreover, possibilities to find alternative employment opportunities are limited, because of their usually poor education, and lack of specialized skills.

On the contrary, in the inclusion situation, the income of the informal primary collectors increases by 40%. This increase is achieved by means of collecting more materials (improved working efficiency). Income increases associated with better quality of materials sold are not taken into consideration.

6.2.8 Remaining life time of adequate waste treatment and disposal facilities

If the informal primary collectors are not allowed to gather recyclable materials, the quantities sent to landfills will increase further and therefore the lifetime of these sites reduces by 2.1% in comparison with the original situation. As expected, the inclusion situation has the opposite effect, bringing as consequence an extended lifetime capacity of landfill sites, by 2.4%.

Figure 6.5 shows the results of the sustainability assessment in a comparative way, using the distance to target approach. The desired value is represented as 100%; largest distance to the target means a largest path to achieve a sustainable system. In the exclusion scenario, the indicator values move away from the targets. The opposite occurs in the inclusion case. The only exception is given by the share of waste management costs in relation to GDP, but as explained above, this does not mean the achievement of sustainability goals. Consequently, as the results show, a total exclusion of the informal sector from the MSW management system has negative effects at different levels of sustainability. In contrast, if there is commitment to work with the waste collectors within their "professional" background, improvements are achieved.

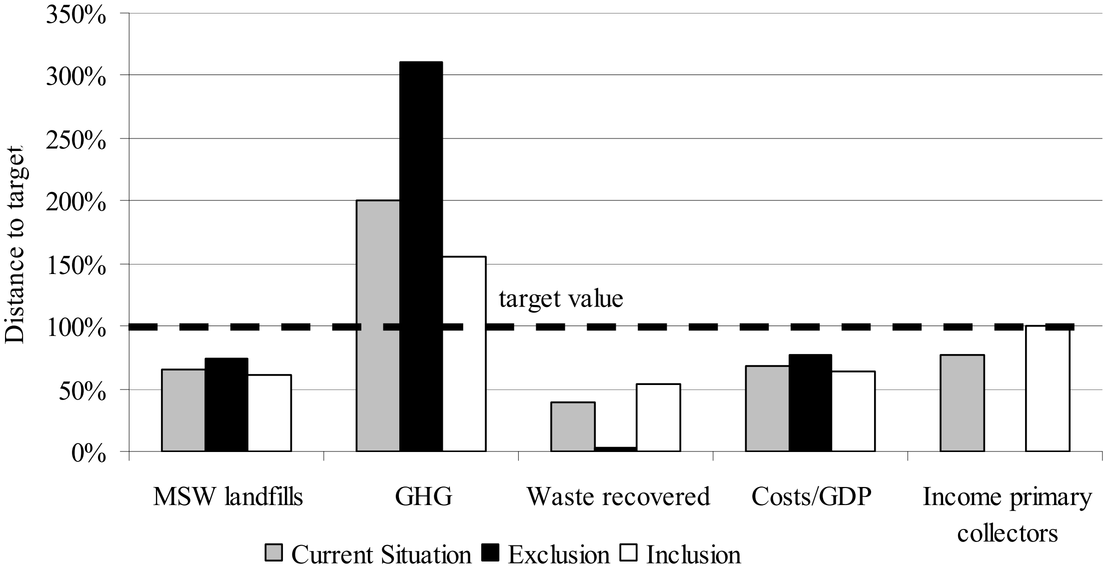


Figure 6.5 Impacts of the informal waste sector on sustainability

The improvements attained in the inclusion scenario correlate with benefits brought by the informal sector, also found in the literature (Van den Klundert 1995, Wilson 2006). These benefits are summarized in three main aspects:

Environmental protection

- Resource management and valorization of recyclables, by returning them into productive chains.
- Conservation of resources and energy, when secondary raw materials are used in manufacturing processes.
- Reducing the amount of MSW arriving at landfills, therefore void space at disposal sites is preserved and negative impacts are reduced.
- Reduction in environmental damage from exploiting primary resources, including mining and deforestation.

Social aspects

- Provision of employment and income-generating activity for a large number of people, many of whom would otherwise be indigent or require financial support from the government.

- Improved health and safety conditions when informal activities are recognized and supported.

Economic aspects

- Reduction of the amount of MSW requiring collection and transport, resulting in less money and time spent on these activities.
- Extension of the lifetime of capital investments, such as sanitary landfills, through reduction of throughput.
- The supplying of raw materials to the local manufacturing sector without foreign exchange or import.

These results should be considered when designing and planning future waste management strategies for the MRS.

6.3 Possibilities of Working Together with the Informal Waste Sector in Latin America

Even though, frequently activities executed by the informal sector are ignored and seen as a problem by authorities in low and middle income countries, in recent years, informal waste workers in several regions have achieved some degree of organization; opening channels to debate about their rights to work in decent conditions within the framework of the public system of waste collection (Waste Pickers without Frontiers 2008). As a consequence, there has been a growing recognition of their activities by local and national organizations, leading to more supportive public policies and acknowledgment of the important work carried out by the waste pickers.

Worldwide, there are several organizations of waste collectors, such as KKPKP, “Kagad Kach Patra Kashtakari Panchayat”, which is a trade union of waste pickers from Pune, India. It originated in 1993 and nowadays it has more than 5,000 registered members. Another example of institutionalized private sector is the Zabbaleen in Cairo, Egypt (Van der Klundert 1995); who with external assistance organized themselves, extending and upgrading the services they offer, which goes from collecting waste, to setting up and operating recycling and composting businesses. The Zabbaleen have also received formal recognition for their services from the municipal government.

It is clear, that there are challenges and constraints that the informal sector must overcome in order to achieve integration into formal systems. Because of its informal nature, it is difficult for informal workers to offer a regular service to enterprises or municipalities. Additionally, municipal government time schedules for contracting and payments might not be adequate to the informal workers, who need a daily income. During the field research carried out in Santiago de Chile, middlemen and organized collectors mentioned that costs and payment of tax, associated with becoming a small-enterprise in Chile were very high and that they do not receive any kind of incentive, associated to the environmental labor they are engaged with (author’s interviews May 2008, November 2009). Commercial registration requirements, labor union rules or labor laws, are usually beyond the informal sector capabilities (Van der Klundert 1995).

Proposals of integration have diverse origins and involve different stakeholders, including specialists in urban management, organizations working for the welfare of pickers, academics and social workers or international organizations (Schübeler 1996). Therefore, the perspective of inclusion suggestions differ, in some cases, the aim is the economic and safe resource recovery and recycling; while in other cases it is aimed to improve the welfare and work of the informal workers.

In order to find possible integration proposals, with transfer and application in the MRS, several cases of informal workers involvement that have been taking place in the last 25 years in Latin America are analyzed in this thesis and are shown next.

6.3.1 The Latin American experience

Given the potential benefits of the informal waste sector, supporting their activities, and achieving their inclusion in the formal waste management system should be an aim in those regions where the sector is active. Nevertheless, there are still no recognized concepts on how to integrate the informal sector over the long term into a recycling orientated waste management system. Nine experiences were selected and roughly classified in four groups:

- Community based recycling activities: “El Ceibo” and “Reciclando Sueños” (Argentina)
- Experiences aiming the inclusion of pickers into an integrated waste management: “Asmare” and “Dois Irmaos” (Brazil)
- Experiences aiming to secure a working place for the informal pickers: “Paracatu Recicla” (Brazil) und “Recuperar” (Colombia)
- Experiences aiming to integrate the pickers into national associations: “AREILS” (Chile) and “Asociación de Recolectores de Bogotá” (Colombia)

These experiences were analyzed at four different levels: policy and regulatory framework, organizational structure, technical conditions and finally the performance of the alliance towards sustainability. They were evaluated using the approach given in Section 3.3, based on the sustainability guidelines described in Chapter 2 (Table 2.4). Information about sustainability aspects of the cooperatives are given in Annex V.

6.3.1.1 Argentina

A new legal framework regarding waste management activities was developed in Buenos Aires, in recent years. In 2002, a new law (Law 922) including several aspects on recycling was published. In this law, the activity of the informal collectors was considered legal; promoting source segregation and environmental education. In 2008, the government of the city of Buenos Aires was planning to start information campaigns to promote source segregation, supporting the collection of recyclables materials by cooperatives of waste pickers (Página 12, 2008). Furthermore, the city of Buenos Aires executes programs to register primary waste collectors, obtaining statistics about people working in the field, as well as characteristics of their job and life conditions.

6.3.1.1.1 Cooperative of Urban Collectors “El Ceibo”, Buenos Aires

The cooperative “El Ceibo” was created in 1989; offering door to door collection services, segregation and commercialization of recyclable materials. One aim of the project was to increase the environmental conscience of the householders, which was achieved by providing relevant information about source separation, benefits of recycling and the importance of the activities carried out by the cooperative (IDB 2005).

One important alliance was created between the collectors, citizens and small businesses. Collectors obtain cleaned segregated materials which are easier to commercialize. The cooperative has alliances with local and national stakeholders and NGOs (Figure 6.6).

Strengths and weaknesses: This way of inclusion has a general positive impact on maintaining the society’s productive potential, contributing specially to increase recycling rates, therefore diverting waste from landfills. This is achieved by introducing training courses to the waste collectors and providing recycling information to householders. More amount of materials, and with a better quality are obtained; hence prices paid by middlemen are better. However, there are still some weaknesses regarding the quality of life of waste collectors and the financial viability of the cooperative, because their negotiation capacity is still reduced, which is reflected in lower incomes.

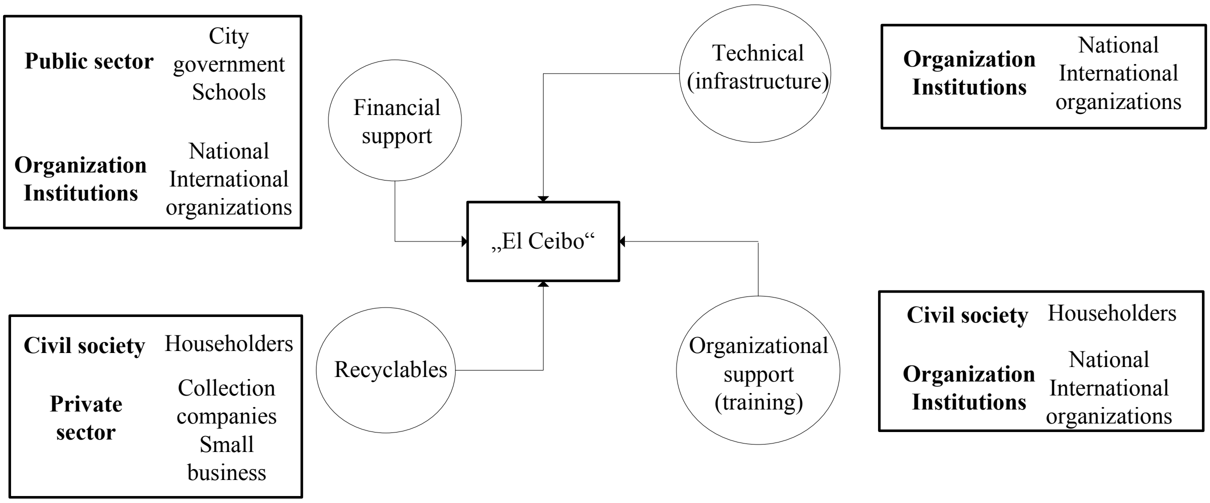


Figure 6.6 Cooperation - "El Ceibo", Buenos Aires

6.3.1.1.2 Cooperative "Reciclando Sueños" (Recycling Dreams), Buenos Aires

The cooperative was created in 2004, when a group of 15 people decided to work together in order to obtain better prices for the materials they collected (Vales 2007). Waste pickers accomplish the collection, transport, separation and commercialization of recyclable materials. Informal workers are supported by neighbors, community organizations and NGOs (Figure 6.7).

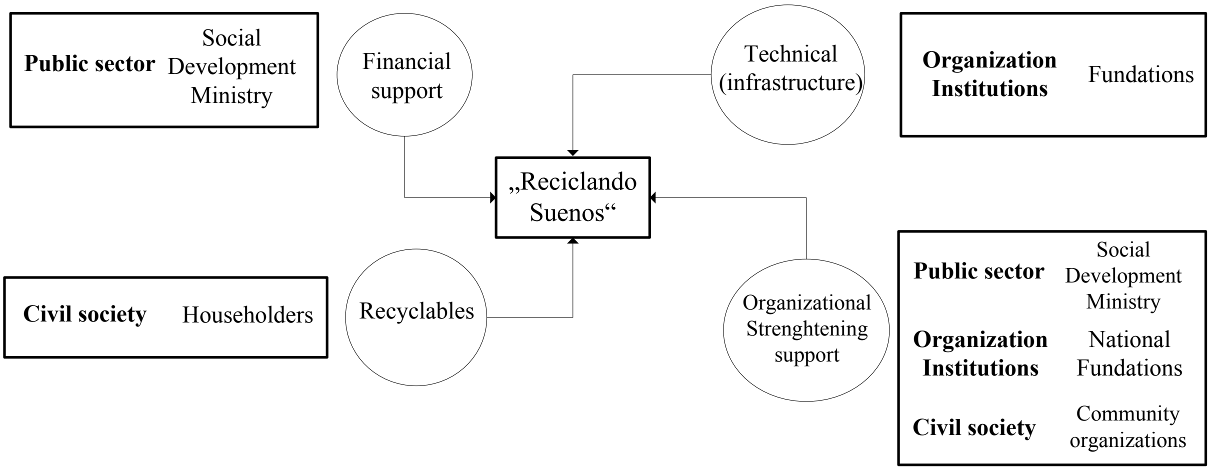


Figure 6.7 Cooperation - "Reciclando Sueños", Buenos Aires

Strengths and weakness: The formation of "Recycling Dreams" contributes with the goal of sparing use of resources. Collection rates of recyclable materials have increased with the additional benefits that less waste is deposited in landfills. Waste collectors are able to obtain better prices in the commercialization phase, and they have increased their negotiation capacity with the acquisition of equipments to treat the solid waste. Their weakness is related to the financial self-sustainability of the cooperative, which is still very dependant on the prices of the materials.

6.3.1.2 Brazil

In Brazil, there is lack of a legal framework for solid waste management at the national level. Nevertheless, at the municipal level some laws have been established to fulfill this lack. A positive aspect is given by a consolidated policy of acknowledgement and organization of informal waste collectors. The occupation of "collector of recyclable materials" is recognized by the Work Ministry of Brazil; and there is a legal framework for the inclusion of the waste collectors in activities of waste management (Lima 2008).

6.3.1.2.1 Associations "ASMARE" (Paper, Cardboard and Recyclables Collectors), Belo Horizonte

"ASMARE" was created in 1990 aiming to improve the working conditions of waste pickers and to decrease confrontations between them and municipal authorities, who did not recognize and obstructed the job carried out by informal collectors at that time (BID 2005).

Nowadays, members of "ASMARE" are in charge of collection, segregation, further preparation and commercialization of recyclable materials. They work in cooperation with the publicly organized MSW management of the city; receiving recyclable materials deposited by householders at the *locations for voluntary delivery* of Belo Horizonte. They have also introduced training courses addressed to people living at the streets, organize meetings with the communities and promote the organization of other collector associations in Brazil (BID 2005).

Since the beginning of the experience, "ASMARE" has established good relations with the NGO Caritas and with the municipality, which has promoted inclusion politics towards informal waste collectors. Other organizations have been engaged in the project; for instance the LIFE program from the United Nations helped with construction of pushcarts and other equipments. The National Fund for the Environment and the Inter-American Foundation helped additionally with financial resources (Figure 6.8).

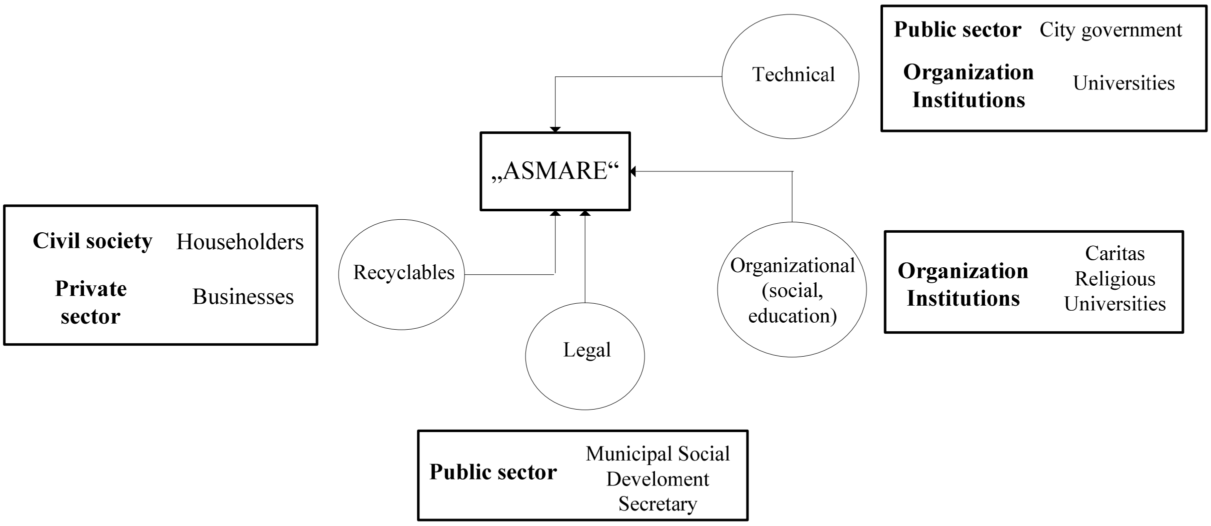


Figure 6.8 Cooperation – "ASMARE", Belo Horizonte

Strengths and weaknesses: This way of inclusion has positive impacts at all levels of sustainability, namely maintaining the society's productive potential, improving quality of life and building capacities for development and action. The organization has been sustainable in time, improving the life and working conditions of the waste pickers and improving their acquisition power and self esteem, through recycling activities. The model implemented since 1993 incorporates waste pickers into the integrated waste management of Belo Horizonte, thanks to the acceptance of authorities and participation of civil society.

6.3.1.2.2 Association "Collectors of Dois Irmaos", Dois Irmaos

This association started in 1994, as an initiative of waste pickers and the municipality. A new waste management system was proposed, including separation of recyclable materials at the source, segregated collection carried out by the municipality and materials separation executed by the informal workers.

The association works in a storehouse, where processing of recyclables takes place. The municipality introduced the segregated collection and transport of materials, to the materials recovery facility (MRF) and the transport of refused materials to final disposal sites. The association is engaged in environmental information campaigns to the population, turning out in higher participation in source separation (BID 2005). This association has a strong alliance with the citizens who participate in the segregation of recyclable materials at the source. This and other strategies of cooperation are shown in Figure 6.9

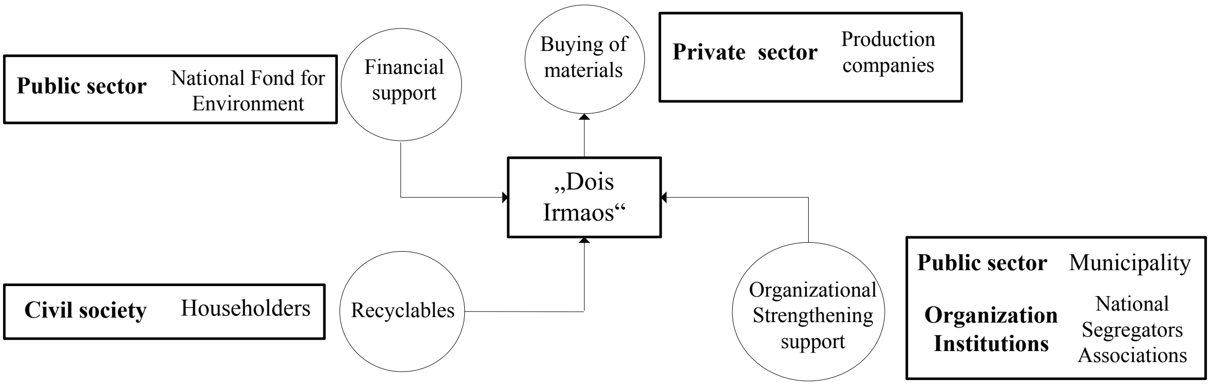


Figure 6.9 Cooperation - "Association of Collectors Dois Irmaos"

Strengths and weaknesses: This way of inclusion contributes with the sustainability guideline of maintaining the society's productive potential, through the conservation of material needs, and building capacities for development and action, referring to the non material needs. Financial viability of the project has been achieved by establishing alliances with strategic companies and with the support from the municipality. The negotiation capacity of the workers has improved, because they are able to provide high quality materials, which has also impacted the income of the workers in a positive way.

6.3.1.2.3 Association "Paracatu Recycles", Paracatu

This association started in 2001, as an initiative of municipal authorities to protect scavengers working in an old landfill, which was going to be closed and to help them to find new working possibilities (BID 2005).

Nowadays, workers are in charge of collection and separation of materials and further commercialization. Door to door collection takes place, in residential and commercial places. In some cases, recyclable materials are delivered by householders to the waste storehouse. Separation of materials takes place at the stock center. Important alliances of this association are shown in Figure 6.10.

Strengthens and weaknesses: As far as the information allows an assessment, this association achieves an improvement in the quality of life of waste pickers and contributes with the building of capacities for development and action. Nevertheless, there are several weaknesses, principally related with maintaining the society's productive potential, because the cooperative does not contribute significantly with the sparing use of resources. The main aim of this cooperation was to secure working places to waste pickers, but it did not consider other aspects to improve their working efficiency.

6.3.1.3 Cooperatives "Cateura" and "Procicla", Asunción, Paraguay

In Paraguay, municipalities are in charge of MSW management. Additionally, aspects related to human health are regulated by the Environment Secretary and Public Health Ministry. Even though, there is a legal framework for MSW management, its control and regulation is still insufficient. In Asunción, the municipality is in charge of collection and final disposal of MSW (BID 2005).

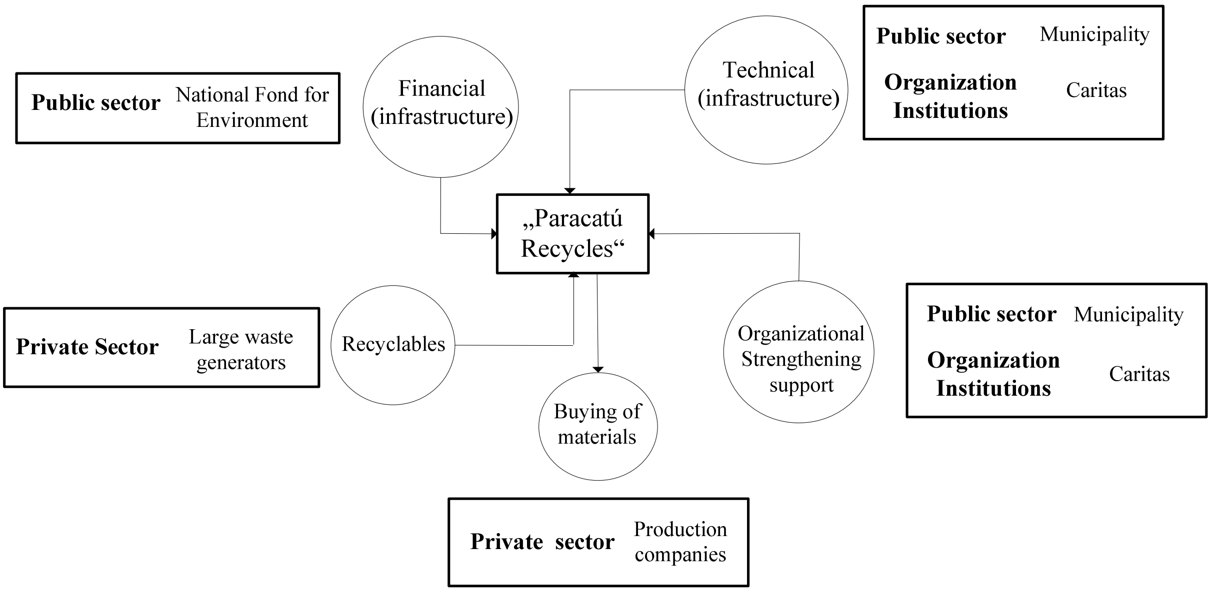


Figure 6.10 Cooperation – “Paracatu Recycles”

With the aim of improving the working and living conditions of the scavengers of the dumping site of Cateura, Asunción, several scavengers organizations were created with the support of the National Workers Center, between 1993 and 1999. Because of the imminent closure of the Landfill Cateura in 2005, a project called “Procicla” was created, in cooperation with scavengers’ unions, the municipality and the NGO Alter Vida (Moreira 2005).

Scavengers working at the landfill collected recyclable materials and carried out their classification, preparation and commercialization. At the landfill, there was not infrastructure available to process or to store the materials.

With the implementation of “Procicla”, waste scavengers changed to collect materials on the city streets. The materials are transported for classification, to a stock center and are finally commercialized. Scavengers’ organizations have links with the municipality, Public Health Ministry and especially with the National Workers Center, as Figure 6.11 shows (BID 2005).

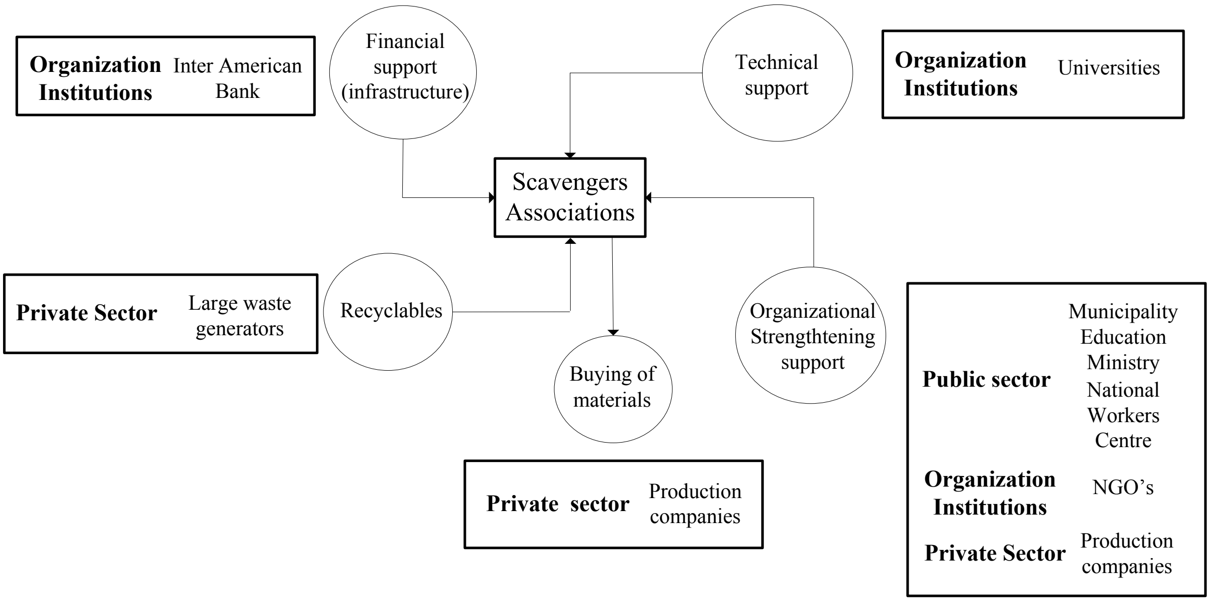


Figure 6.11 Cooperation - Project “Procicla”, Asunción, Paraguay

Strengthens and weaknesses: The program had a positive impact in the improvement of working and living conditions of waste collectors. Moreover, in environmental terms it contributes with better recycling rates, thus protecting resources. Weaknesses are related with the lack of public policies, and investment in the waste management sector. Financial viability of the project is as well questionable.

6.3.1.4 Colombia

Colombia has approximately 50,000 scavenger families that earn their livelihood in collecting solid waste (UNESCO undated). In 1990, a program was launched to organize the waste pickers in local associations by the local NGO Social Foundation. The purpose was to help the waste pickers to improve their working conditions through enhancing their transport means and quality control systems for selected waste. The program also addresses social needs such as child education, access to the social security system and issues related to women.

The National Collectors Association (ANR for its Spanish abbreviation) has implemented facilities for storing waste and has developed solid waste management systems within the communities. The program organizes waste collectors in local associations. A few of ANR branches have evolved in their respective cities and are developing an integral management program of MSW with local communities. The process of organization, equipment provision and development of adequate technologies brings about an increase of approximately 30% of the scavengers' revenues (UNESCO undated).

6.3.1.4.1 Association of “Recicladores de Bogotá (ARB)” (Waste Recyclers of Bogotá) Bogota, Colombia

In 1987, the city of Bogota was planning to implement the privatization of certain waste management activities, which would negatively affect the job possibilities of the waste pickers of the city (Ciudades para un futuro más sostenible 2006). For this reason in 1990, waste collectors started an organizational process to promote better working and living conditions, aiming to be recognized as important actors of the waste management system.

Activities carried out nowadays, by the waste pickers include collection, transport, classification, transformation and commercialization of recyclable materials. Moreover, the ARB and other recyclers’ cooperatives are participating in a pilot program for the management of a recycling center (La Alquería) located in Bogota (Veira 2008). Information campaigns have taken place promoting segregation of valuable materials at the source. Waste pickers working at La Alqueria have got benefits, such as a minimum salary and social security (Veira 2008). Strategy alliances created by this organization are shown in Figure 6.12.

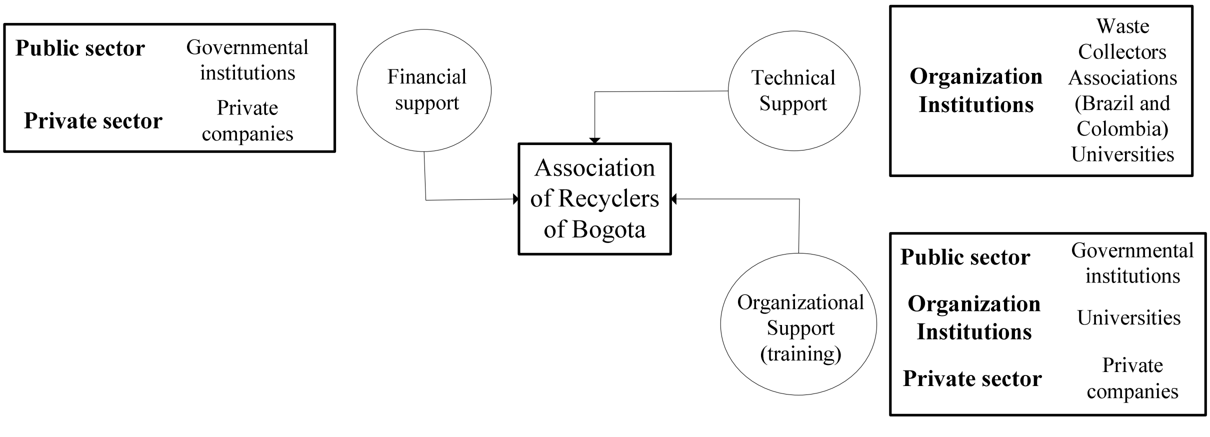


Figure 6.12 Cooperation - Association of “Waste Recyclers of Bogota”

Strengthens and weaknesses: The formation of the "Association of Recyclers of Bogota" contributes with several goals of sustainability in waste management, particularly with the sparing use of non renewable materials, development of human and knowledge capital and increasing the possibilities of independence existence. There are however some weaknesses related with the financial viability of the cooperative and health and safety aspects of the workers.

6.3.1.4.2 Cooperative "Recuperar", Medellin, Colombia

The first cooperative of informal collectors in Medellin was created in 1983, as a consequence of the closure of the dumping site Moravia, where 320 families lived and worked (Fundación Corona 1996). To find a solution to the situation some waste pickers, together with the City Mayor, private companies and citizens decided to create the Cooperative "Recuperar".

Nowadays, the Cooperative "Recuperar" is one of the most successful in Colombia and Latin America (Medina 2000). The cooperative provides MSW services, including collection of mixed waste and source separated recyclables. Moreover, it operates its own MRF, and also provides other services such as cleaning and gardening services to local public and private entities, and runs its own temporary employment agency.

In 2006, another cooperative was formed, "Recimed', in cooperation with the municipality. The project introduced a large information campaign to promote source separation and recognition to waste pickers (Olivares 2009). Additionally, one more organization of waste pickers exists in the city of Medellin, called "Arreciclar". Strategic alliances created by these cooperatives are shown in Figure 6.13.

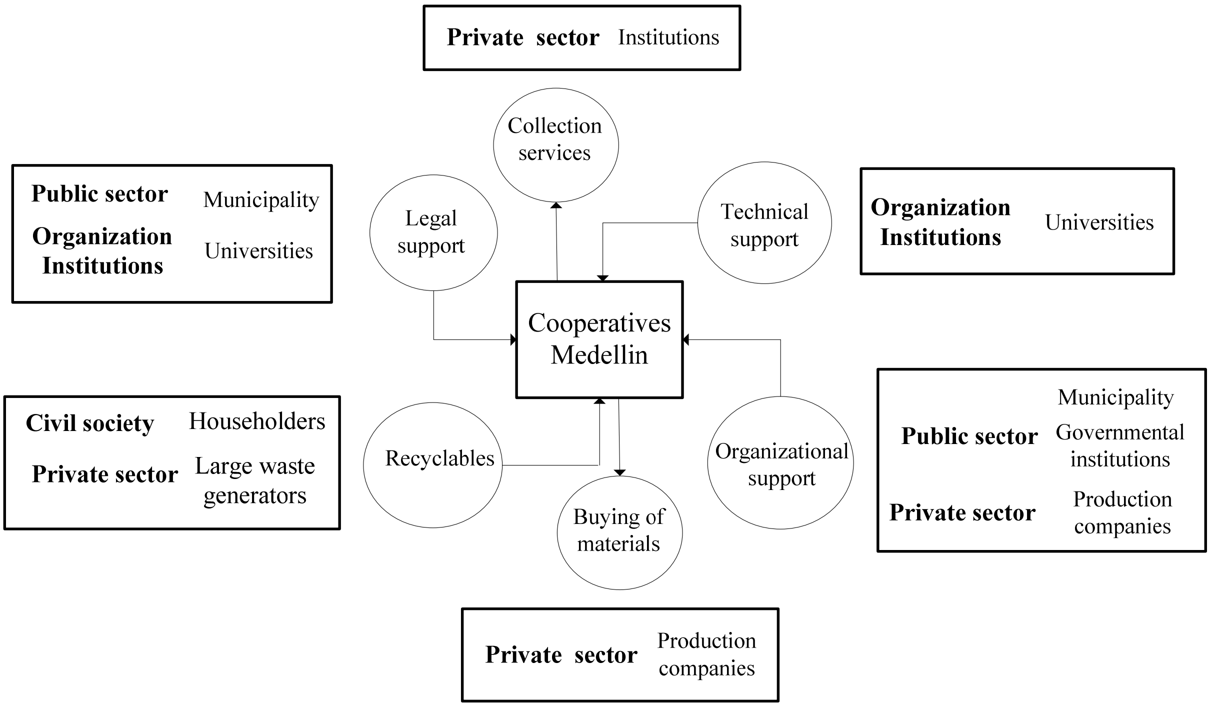


Figure 6.13 Cooperation - Cooperatives in Medellin

Strengthens and weaknesses: The formation of "Recuperar" contributes with all the aspects of sustainable development. Because of the good performance of the cooperative, two other waste pickers' cooperatives have been formed in Medellin with good results. "Recuperar" expanded their services outside recycling activities, which allowed them to achieve financial viability.

6.3.1.5 Association "Recolectores Ecológicos Independientes de La Serena (AREILS)" (Independent Ecological Collectors of La Serena), La Serena, IV Region, Chile

The association started activities in 2000, thanks to the support of the National Collectors Association of Chile, who contacted them and provided information about how to work in an organized way. The collectors of La Serena were then able to create their own organization with the support of the municipality.

The association carries out collection, separation, processing of recyclable materials and their commercialization. Collection takes place on the streets and directly from large waste generators, like supermarkets or commercial centers. They also receive materials at the storehouse, collected by waste pickers who do not belong to the organization or directly by householders.

The association has worked with CONAMA in recycling programs, performing at the same time information campaigns and environmental education programs addressed to citizens. The collectors of La Serena have several contacts with other national and international scavengers associations and with other important groups as Figure 6.14 shows.

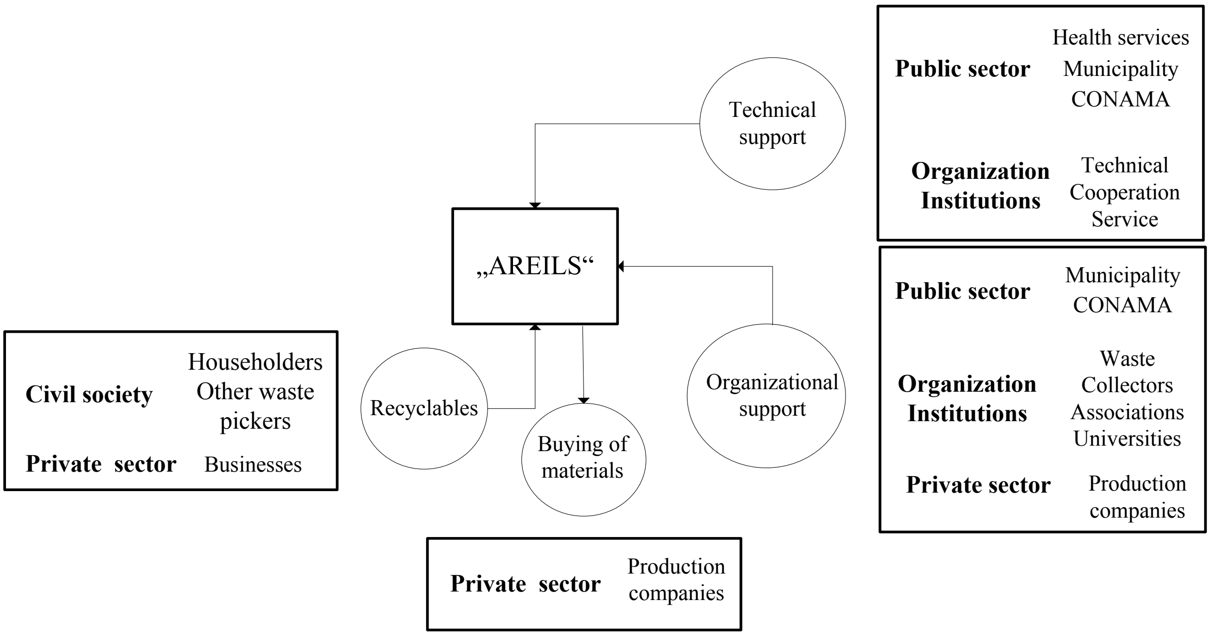


Figure 6.14 Cooperation – "AREILS"

Strengthens and weaknesses: The formation of AREILS provides improvements in important aspects of sustainability, such as contributing to maintain the regeneration capacity of natural systems. AREILS is able to collect and recover large amount of waste materials to be recycled and it is a stable and trustworthy stock center, for buying and selling materials. This goal was obtained thanks to good alliances with private companies and several kinds of trainings. The development of human capital has also improved, due to the existence of a regulatory framework and implementation of training courses to the collectors. The possibilities of independent existence of waste collectors have increased after the formation of AREILS. Weakness related with the minimization of adverse health impacts, primarily because of lack of health insurance.

Summary of the results

Each experience was evaluated on the basis of the Integrative Sustainability Concept, by using the indicators given in Table 3.16, at the regulatory, organizational, technical, and performance level. Values of 0, 0.5 and 1 were assigned to each level and each sustainability goal. A value of 0 represents the worst case; whereas a value of 1 represents the best case. The values were then added for each sustainability guideline, to obtain an aggregate value. Table 6.3 shows the assessment results of the analyzed experiences.

Table 6.3 Summary of organization experiences in Latin America

Name		Sparing use of non renewable resources	Maintaining the regeneration capacity of natural systems	Development of human and knowledge capital	Minimization of adverse health impacts	Financial viability	Possibility of independent existence
El Ceibo (Argentina)	R	1	1	0	0	0	1
	O	0	0	1	0	0.5	N/I
	T	1	0	0	N/I	0	0
	P	1	1	1	N/I	N/I	0.5
9		**3**	**2**	**2**	**0**	**0.5**	**1.5**
Recycling Dreams (Argentina)	R	1	1	1	N/I	N/I	1
	O	N/I	0	1	N/I	0.5	N/I
	T	1	N/I	N/I	1	N/I	1
	P	1	1	1	N/I	0.5	1
13		**3**	**2**	**3**	**1**	**1**	**3**
ASMARE (Brazil)	R	1	0	1	N/I	1	1
	O	1	0	1	N/I	1	0
	T	1	N/I	1	1	1	1
	P	1	1	1	1	1	1
18		**4**	**1**	**4**	**2**	**4**	**3**
Dois Irmaos (Brazil)	R	1	0	1	N/I	1	N/I
	O	1	0	1	N/I	1	1
	T	1	1	N/I	1	1	1
	P	1	1	1	1	0.5	1
17.5		**4**	**2**	**3**	**2**	**3.5**	**3**
Paracatu Recycles (Brazil)	R	0	0	N/I	N/I	N/I	0
	O	1	0	N/I	N/I	0.5	0.5
	T	0	0	N/I	N/I	N/I	1
	P	N/I	0	N/I	1	N/I	1
5		**1**	**0**		**1**	**0.5**	**2.5**
Procicla	R	0	0	1	0	0	0
	O	1	0	1	0.5	1	0.5
	T	0.5	0	0	1	1	1
	P	1	1	1	1	0	1
13.5		**2.5**	**1**	**3**	**2.5**	**2**	**2.5**
ARB (Colombia)	R	1	1	1	N/I	N/I	1
	O	1	0	1	1	0.5	1
	T	1	0	1	N/I	N/I	1
	P	1	1	1	N/I	1	0.5
16		**4**	**2**	**4**	**1**	**1.5**	**3.5**
Recuperar (Colombia)	R	1	1	1	0.5	1	1
	O	1	0	1	1	1	1
	T	1	0	1	1	1	1
	P	1	1	1	1	1	1
21.5		**4**	**2**	**4**	**3.5**	**4**	**4**
AREILS (Chile)	R	1	0	1	0.5	1	1
	O	1	0	0.5	0.5	1	1
	T	0.5	0	1	1	1	1
	P	1	1	1	1	1	1
19		**3.5**	**1**	**3.5**	**3**	**4**	**4**

R: regulatory/policy level N/I: no information
O: organizational level T: technological level P: performance

These experiences show that the organization, and the inclusion of the informal sector is possible and that the experiences contribute towards the achievement of the sustainable development goals as defined through the guidelines for municipal solid waste management.

6.3.2 Informal primary collectors inclusion model

The evaluation of the selected experiences allows identifying common characteristics and conditions required for the organization of the informal primary collectors, in addition to key factors of success, which are summarized next.

Policy/Regulatory level

- Existence of a legal, regulatory framework for the informal waste sector.

Organizational level

- Implementation of extensive information and awareness campaigns to the community facilitates their collaboration with the recycling program and helps to accept the work carried out by the primary collectors.
- Existence of alliances with production companies guaranteeing a reliable industrial market for secondary raw materials.
- Existence of transparent ways of costs recovery.
- Organizations and inclusion projects should receive support, during the building up and development phase.

Technical level

- Collection of more than one sort of recyclable materials gives more opportunities of commercialization.
- Expansion of activities beyond collection of recyclables, towards further processing and upgrading to add more economic value to materials collected.
- Contribution towards a better performance of the activities carried out by the pickers was achieved due to the segregation of materials by householders at the source.
- Existence of infrastructure to store materials and equipments to process them, improved the negotiation capacity of the waste pickers.

In most of the cases, the primary waste collectors established strategic alliances with important actors, such as local or national authorities, NGOs, governmental institutions, universities, national waste picker movements, civil society, production companies and large waste generators. The commitment of the diverse actors is important to extend and add social and economic value to the system. These alliances, together with the common conditions identified, allow to define a general model of integration, depicted in Figure 6.15.

As observed the model includes cooperation between the different stakeholders involved in waste management, which can be grouped according to (Grafakos et al. 2001) in the following groups:

- Public sector, including national, regional and local governments: the role of the public sector should be to create adequate conditions for a more effective MSW management service. In the model, this inclusion would increase the awareness of the civil society in recycling issues and the regulation and monitoring of establish cooperation, among actors.

- Private sector, including large waste generators and production companies: this group plays an important role in the delivering of constant waste flows to primary collectors, establishing contracts with them for the collection services. In addition, manufacturing industries represent a potential purchaser for the secondary raw materials recovered.

Additionally, because of its access to financial resources, they are able to provide training to waste pickers to improve their working efficiency.

- Civil society plays an important role in the delivering of source separated materials and represent a key factor in accepting the work of the primary collectors.
- Organizations and institutions who can work directly with the primary collectors and can be involved in promotion, rising of awareness, decisions making and coordination between the informal and the formal MSW management systems.
- Small scale private sector, including primary waste collectors and middlemen: in the model, a large cooperation between these two groups is suggested. Taking advantage of the fact, that usually middlemen own already material recovery facilities and are logistically situated between primary collectors and production companies. These MRF present the potential to function as stock center for the materials collected by waste pickers. Agreements between them could facilitate the recognition of middlemen as environmental-recycling actors, and not only as businessmen. Moreover, credits given by the public or large scale private sector can be offered to middlemen working in close cooperation with primary collectors, for the acquisition of equipments and machines to process the recovered materials.

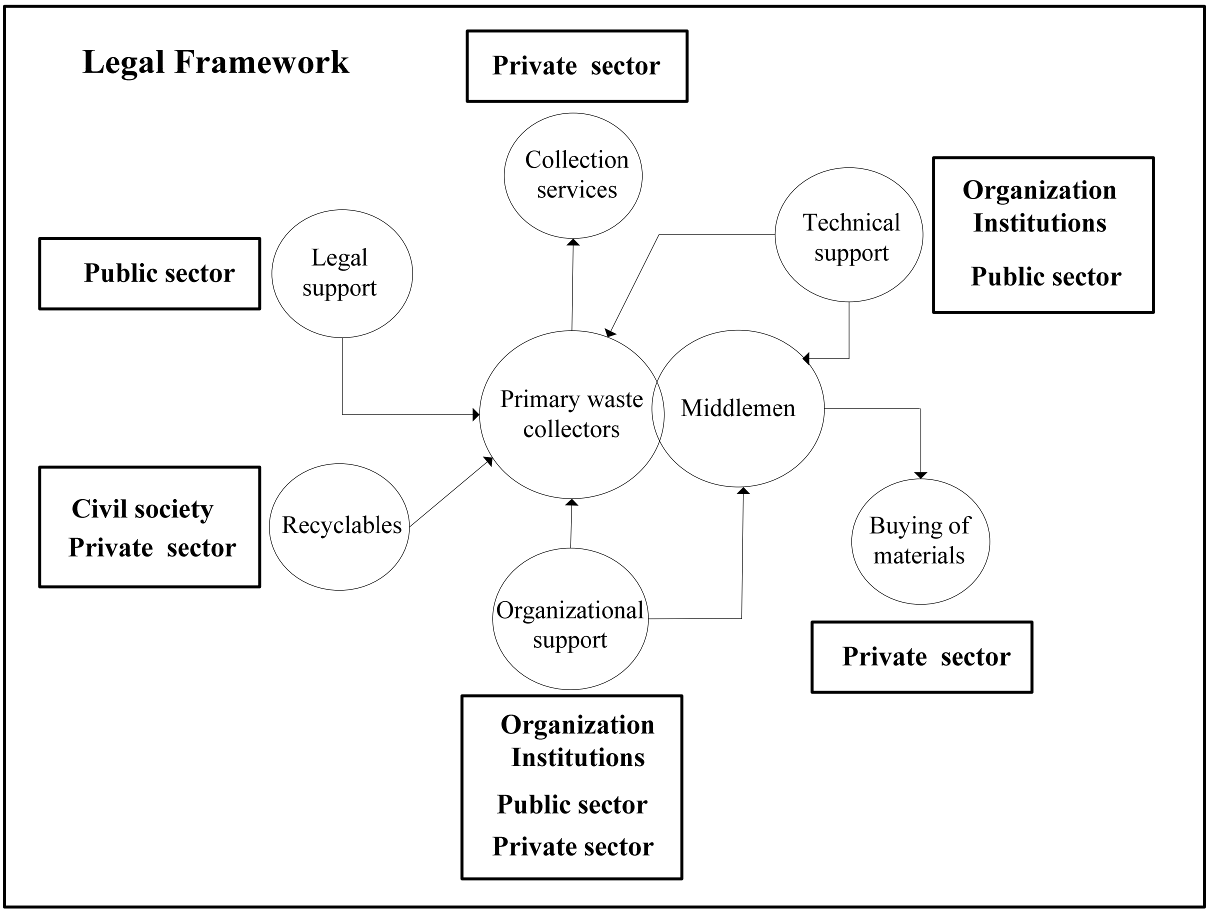


Figure 6.15 General model of inclusion for the primary waste collectors

6.4 Perspectives

The demand for secondary raw materials in Santiago de Chile is high, and it is essentially supplied by the informal actors. It has been shown, that the informal sector plays an important role in the collection, sorting and commercialization of recyclable materials, in particular paper, cardboard and metals, within the municipal solid waste management in the Metropolitan Region of Santiago. The involvement of the informal workers in recycling is, however, driven by economic more than by environmental reasons.

A total exclusion of the informal waste sector has significant negative repercussions on the sustainability of the MSW management system. On the other hand, even though recovery targets cannot be achieved only by improvements in the informal recycling system, participation and involvement of this group are of special importance to create a sustainable system.

It is essential, to open channels of communication between formal and informal actors and to encourage working cooperation between them. Additionally, it is important to grant economic sustainability to projects involving primary collectors, not only by obtaining credits, but also by creating business models and future development plans.

The results of the sustainability analysis of the exclusion and inclusion cases serve as basis for the development of future scenarios of MSW management for Santiago de Chile. However, it is important to notice that the organization of the informal sector is feasible if certain framework conditions take place, this is the reason why the organization of the informal workers is not considered in all scenarios developed.

Chapter 7

Municipal Solid Waste Management Scenarios

In this Chapter, the analysis of three different scenarios of MSW management in Santiago de Chile is presented. A qualitative description of the scenarios is provided, in addition to the results of waste generation and waste composition for each scenario. Results of the sustainability evaluation are as well provided. Finally, results of a sensitivity analysis are given.

7.1 Framework Scenarios within the Risk Habitat Megacity Project

Within the Risk Habitat Megacity Project three explorative framework scenarios were developed: *Business as Usual (BAU), Collective Responsibility (CR) and Market Individualism (MI)*. These framework scenarios gave a general description of the social, technological, economic, environmental and policy governance of Santiago de Chile in the year 2030. These scenarios were characterized by *drivers*, underlying causes of change and *storylines* which described the qualitative assumptions about such drivers. The tendencies for these drivers of change are found in Annex B.

The development of the framework scenarios was independent of the current work, but they served as a basis for the development of the contextualized MSW management scenarios for Santiago de Chile, presented in this Chapter.

7.1.1 Keywords for municipal solid waste management scenarios

To work out a description of the MSW management scenarios for Santiago de Chile in 2030, those driving factors and keywords influencing solid waste management were selected, within the present research work. They constitute the base for the MSW management storylines and quantitative variables further developed. A description of the driving factors and their influence on residues management is given next.

7.1.1.1 Economic development

Within the economic development category, the driving factor integration into the world market and keyword degree of liberalization are selected. This category is selected because there is a certain correlation between the degree of economic development of a region and the generation and composition of MSW produced (Beigl et al. 2003, Vehlow 2008b). Additionally, the *degree of liberalization* is an important driver of change, because of its influence on the strengthening of private competition. Free market competition encourages larger availability of waste services suppliers (collection, treatment, disposal services).

7.1.1.2 Institutional framework/governance

Within the Institutional framework/governance category, the driving factors selected are the national level, with keywords market and State role; local government, with keywords municipal role and degree of collaboration between municipalities; civil society role with its level of civil society influence; private sector role, and its influence in the economy and informal dynamics, and its importance of informal decision making/actions.

The institutional framework and governance is an significant aspect of MSW management, able to assign responsibilities and roles of the different actors involved in providing waste treatment and management services.

The keywords *State role* and *market role* differentiate between regulations established according to market influence or imposed by the State. Aspects related with these keywords are the development and application of incentives towards alternative waste treatment technologies, integration of the informal sector, recycling, or waste to energy technologies.

The *municipal role* and *degree of collaboration between municipalities* are selected because the responsibility of managing municipal solid waste in the MRS occurs at the local level (e.g. to collect waste from households regularly, to store it, to recycle it, or to dispose of waste appropriately). Additionally, the coordination between municipalities has an influence on economies of scale, which may be favorable for alternative waste recovery and treatment technologies.

The next keyword, is the *level of civil society influence*. Householders are one of the most important actors in accepting MSW management strategies and participating in them, recycling systems, demanding appropriate services and accepting the informal workers.

The private sector is an important actor in providing MSW management services in Santiago de Chile. Additionally, private industries influence the market of recyclables by consuming secondary raw materials. For this reason, the keyword *influence of private sector in the economy* is selected.

Finally, the keyword *importance of informal decision making /actions* is selected because of the significant role of the informal sector in MSW management in Santiago de Chile.

7.1.1.3 Demographics

Within the category demographics, the change of urban population is selected. Associated keywords are the total as well as the urban population change.

Population growth directly affects the amount of waste. Moreover, changes in urban population also affect consumption patters, which in turn affect the specific waste generation and the waste composition, therefore having affecting future waste management technologies.

7.1.1.4 Technological development

Within the category of technological development, the selected driving factors are the role of technologies, in relation to other solution approaches to the problems, including cost situation, and the guiding vision of technological promotion, with social acceptance and emphasis on hi-tech over intermediate tech as keywords.

The technological development impacts innovations in production processes, generating less waste quantities on one side, and in the development of advanced waste treatment technologies, on the other side.

Additionally, the selected solid waste treatment and disposal methods would depend on their social acceptance and on the level of technological development required for its implementation.

7.1.1.5 Societal value systems

Within the category societal value systems, the selected driving factor is the consumption patterns and its relation between material vs. non material consumption.

Changes in society’s values produce changes in consumption patterns, altering the magnitude of the demand for certain product and services, which in turn generate changes in solid waste quantity and quality.

7.1.1.6 Education

Within the category education, the selected driving factor is the access to it, and the equitable distribution between societal groups.

Education may effect the perception of MSW management, encouraging participation in recycling programs, separation of recyclable materials, and acceptation of the informal sector. An equitable distribution of education, between societal groups, is expected to positively impact the environmental awareness of the population, and this might increase participation in minimization of the waste production and recycling programs.

The analysis of the trends for the selected keywords in each framework scenario, and their effects on different aspects of MSW management turned out in the specific storylines for MSW management in Santiago de Chile.

7.2 Assessment of MSW Management Technologies

Appropriate treatment technologies are selected, in order to define the waste management scenarios for Santiago de Chile. The scenario storylines give a qualitative description of the waste management in the MRS. For the selection of the specific waste treatment technology, the methodology described in Section 3.4.3 was used. The results of the analysis, including technological, environmental and economic aspects are given next.

7.2.1 Biological treatment technologies

Composting and anaerobic digestion technologies were compared for the biological treatment of biowaste.
Technological, environmental and economic parameters of composting and anaerobic digestion were compared. Comparative values of "cero" or "one" were assigned to the less or more sustainable results, respectively (based on the results presented in Table 7.1 to * avoided **by fossil substitution with biogas**
Table 7.3). If composting and anaerobic digestion presented similar results, a value of "one" was assigned to both technologies. This is how the values presented in Table 7.4 were obtained. The average corresponds to the mean value for technical, environmental or economic aspects. These averages are used in a further step, for the selection of technologies in each scenario and they represent the input of the technology selection matrix.
The mass and energy balances of these two processes are shown in Table 7.1. Environmental parameters shown in Table 7.2 were calculated as explained in Section 3.2.2.3.2 and Section 3.2.2.3.3 Economic parameters shown in * avoided **by fossil substitution with biogas**

Table 7.3 were calculated as explained in Section 3.4.3.3.

Table 7.1 Technical parameters – biological treatment

Parameter		Composting	Anaerobic Digestion
Residues to landfill*	[%]	3	2
Compost produced*	[%]	28	27
Recovered metals*	[%]	0.5	0.5
Losses*	[%]	68.5	51.5
Biogas*	[%]	-	19
Electricity generation	[kWh/$\mathrm{Mg_{biowaste}}$]	-	224
Heat generation	[kWh/$\mathrm{Mg_{biowaste}}$]	-	476

* as percentage of input to the plant

Table 7.2 Environmental parameters – biological treatment

Parameter		Symbol	Composting	Anaerobic Digestion
Gross GHG emitted	[kgCO$_{2eq}$/ Mg$_{biowaste}$]	(Em_P)	58	20
GHG avoided*	[kgCO$_{2eq}$/ Mg$_{biowaste}$]	(Em_A)	-6	-60
Net GHG emitted	[kgCO$_{2eq}$/ Mg$_{biowaste}$]	(Em)	52	-40

* avoided by fossil substitution with biogas

Table 7.3 Economic parameters – biological treatment

			BAU (θ^*= 1.2)		CR (θ =1)	
Parameter		Symbol	Composting	Anaerobic Digestion	Composting	Anaerobic Digestion
Capital costs	[US$ 2008/ Mg$_{biowaste}$]	(C_C)	144	141	144	141
Gross production costs	[US$$_{2008}$/ Mg$_{biowaste}$]	(C_P)	25	36	22	31
Revenues electricity sale	[US$/ Mg$_{biowaste}$]		-	34	-	34

* θ overhead and benefits: this value varies according to the management of the installation adopted by the local authority

Table 7.4 Evaluation of biological treatment technologies

	Composting	Anaerobic Digestion
Technical aspects		
Residues to landfill	1	1
Compost	1	1
Recovered metals	1	1
Energy generation	0	1
Average*	**0.75**	**1**
Environmental aspects		
NET GHG	0	1
Average*	**0**	**1**
Economic aspects		
Capital costs per plant	1	1
Gross Production costs	1	0
Revenues electricity sale	0	1
Average*	**0.67**	**0.67**

* These values are used in the selection matrix presented in Table 7.11

7.2.2 Waste to energy treatment technologies

For the recovery of energy from waste, four cases were assessed including incineration with electricity generation, and mechanical biological treatment with three different layouts: biodrying, anaerobic digestion and a combination of both. Because it is assumed that in every scenario the landfill gas (LFG) is used as an energy source, it was not compared with the other waste to energy alternatives.

Table 7.5 shows the mass and energy balances of the mentioned technologies. The balances were derived with information provided in Sections 3.4.3.1.3 to 3.4.3.1.6.

Table 7.5 Technical parameters – energy recovery

Parameter		Incineration Electricity	MBT – biodrying	MBT AD	MBT biodrying/AD
Residues to landfill*	[%]	8	21	53	13
Recycling construction*	[%]	16	-	-	-
RDF*	[%]	-	40	-	40
Recovered metals*	[%]	0.4	0.4	0.4	0.4
Emissions*	[%]	Flue gas	38.4	40	40
Biogas *	[%]			6.6	6.6
Electricity generation	[kWh/ Mg_{MSW}]	621	-	67	67
Heat generation	[kWh/ Mg_{MSW}]	-	1,600	-	1,600 (RDF)

* as percentage of waste input to the plant

Environmental parameters shown in Table 7.6 were calculated as explained in Sections 3.2.2.3.4 and Section 3.2.2.3.5.

Table 7.6 Environmental parameters – energy recovery

		Symbol	Incineration Electricity	MBT – biodrying	MBT AD	MBT biodrying/ AD
GHG produced	[kg CO_{2eq}/ Mg_{MSW}]	(Em_P)	462	285	38	295
GHG avoided	[kg CO_{2eq}/ Mg_{MSW}]	(Em_A)	-165	-440	-18	-493
Net GHG	[kg CO_{2eq}/ Mg_{MSW}]	(Em)	297	-155	20	-198

Economic parameters shown in Table 7.7 were calculated as explained in Section 3.4.3.3 for the respective treatment technology.

The same procedure to select the biological waste treatment was used to choose the waste to energy recovery technology. In this case, comparative values from “cero” to “three” were assigned from the less to the more sustainable results, for each technological, environmental or economic parameter (Table 7.8). These parameters represent the input of the selection matrix (Table 7.17) for the assessment of the waste to energy technologies. These values are used in a further step for the selection of technologies in each scenario. These results are analyzed within the framework conditions of each scenario, in order to select appropriate technologies in each case.

Table 7.7 Economic parameters - energy recovery

			Incineration Electricity	MBT – biodrying	MBT AD	MBT biodrying/ AD
Capital costs	[US$ 2008/ Mg_{MSW}]	(C_c)	445	218	364	314
Production costs	[US$$_{2008}$/ Mg_{MSW}]	(C_p)	69	66	87	72
Revenues electricity sale	[US$/ Mg_{MSW}]		94	-	26	26

Table 7.8 Evaluation for energy recovery technologies

Characteristic	Incineration Electricity	MBT – biodrying	MBT AD	MBT AD/biodrying
Technological				
Residues to landfill	3	1	0	2
Recycling construction	1	0	0	0
RDF	0	1	0	1
Recovered metals	1	1	1	1
Electricity generation	2	0	1	1
Heat generation	0	1	0	1
Average*	**1.17**	**0.67**	**0.33**	**1.00**
Environmental				
Net GHG	0	2	1	3
Average*	**0**	**2**	**1**	**3**
Economic				
Capital costs per plant	0	3	1	2
Gross production costs	2	3	0	1
Revenues electricity sale (US$/$Mg_{MSW}$)	2	0	1	1
Average*	**1.33**	**2.00**	**0.67**	**1.33**

* these values are used in the selection matrix presented in Table 7.16

7.3 MSW Management Scenario: Business as Usual

7.3.1 Storyline

This scenario is characterized by a steady increase of liberalization and privatization trends, with strong market forces, in addition to a material consumption culture. Acquisition of ready available products is very common. Environmental laws and regulations, in the waste management sector are weak and flexible. Waste recovery targets are achieved by improving recycling and biological treatment. Increase of climate change prevention policies promotes the collection and use of landfill gas as renewable energy source.

With help of the civil society and NGOs, new recycling programs with participation of the primary informal collectors are developed, which creates a favorable framework for acceptance of the informal workers in some communities. However, the informal waste sector, even if continuing to play a significant role in recycling, is only partially integrated into the formal waste systems.

The technological advancements encourage the application of alternative treatments for the biogenic fraction of the residues. Technology developments have improved efficiency of landfill gas collection, contributing to increase the share of renewable energies in the electricity network.

7.3.2 MSW landfilled

On the basis of the previous storyline, a quantitative scenario is developed. In the baseline calculation, the specific MSW generation (e.g. landfilled) is calculated as a direct function of the gross domestic product of Santiago de Chile in purchase power parity terms, as economic parameter, as explained in Section 3.4.2.1.

Figure 7.1 shows the quantity of MSW landfilled between the years 2010 and 2030, calculated with Equation (45). The value for the year 2030 is 1.2 kg/(person·day), which is nearly 35% larger than the value in 2007. The resulting increase in the per capita flux of waste deposited in landfills is attributable only to the effect of economic development taking place in Chile (e.g. Santiago de Chile) within this scenario.

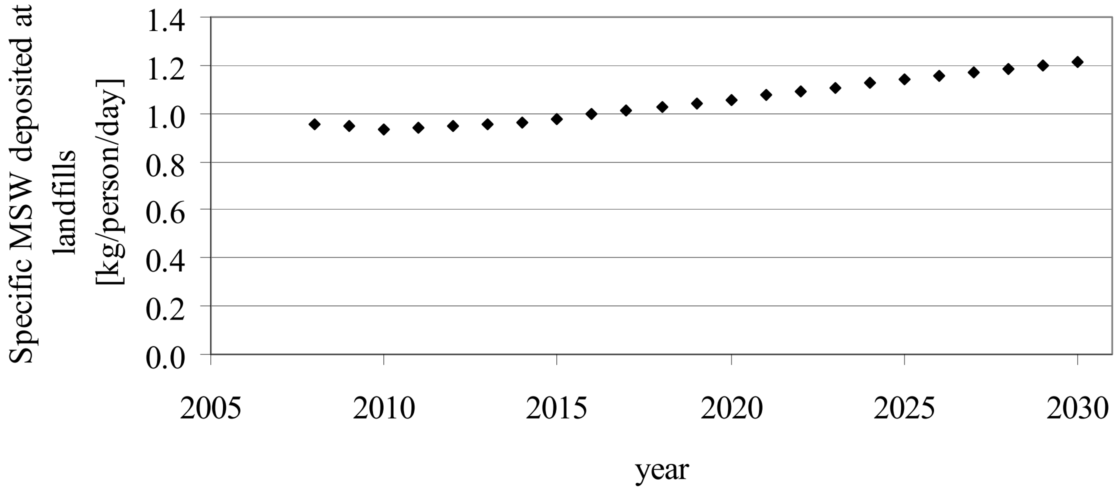


Figure 7.1 Specific MSW deposited at landfills – BAU scenario

7.3.3 Waste generation

Equation (46) allows calculating the quantity of MSW recovered in the BAU scenario. A significant increase is observed from a value of 0.17 kg/(person·day) to 0.60 kg/(person·day) in the year 2030.

Knowing the flux of waste landfilled and waste recovered, it is possible to obtain the specific waste generated in the BAU scenario for the year 2030 (Equation 47). The total amount is then obtained with the population of the MRS (8.0 million inhabitants in BAU) and with the quantity of green and yard waste, which was not used in the determination of the specific MSW generation (355,000 Mg/year), because it is assumed that this value is independent of population growth. These results are shown in Table 7.9.

Table 7.9 Generation of MSW in BAU scenario

Variable		MSW generated ($_{BAU}$)	MSW landfilled ($_{LBAU}$)	MSW recovered ($_{R\text{-}BAU}$)
MSW flow (M^*)	[Million Mg/year]	5.6	3.8	1.8
MSW flow	[%]	100	69	31
Specific[a] (M)	[kg/(person·day)]	1.8	1.2	0.6
Specific[b]	[kg/(person·day)]	1.9	1.3	0.6

a: calculated with Equations (45) to (47), b: corresponding to the total waste generated

The generated MSW flux increased from 1.1 kg/(person·day) in 2007 to 1.8 kg/(person·day) in 2030, resulting in an annual growing rate of 3.0%. Additionally, the recovering rate obtained is 31%.

7.3.4 Waste composition

Table 7.10 shows the waste composition for the BAU scenario in the year 2030. This composition is obtained following the approach explained in Section 3.4.2.3.

Table 7.10 Composition of MSW – BAU scenario

Waste fraction	Composition [%]
Food waste	23
Yard waste	6
Paper/cardboard	29
Plastics	13
Glass	5
Metals	8
Other	16

7.3.5 Municipal solid waste mass flow

Different waste management measures are implemented in this scenario. Based on the respective storyline these measures include:

- A fraction of the mixed waste collected is diverted to mechanical sorting plants, with the aim of recovering materials or energy, before landfilling. Currently, two of the three private companies owning landfills in the MRS are planning the building of such plants with a capacity of 15% of the MSW sent to landfills. The value assumed for 2030 is 26% of the mixed waste collected.
- A fraction of 7.5% of the MSW flow generated is collected through drop-off systems. Only drop-off systems for paper and glass are considered, because of the higher participation of citizens in the separation of these materials.
- A fraction of the MSW flow generated is sent to publicly organized sorting plants. The capacity of these plants is five times larger than current installed capacities.
- Informal collectors are organized and carry out collection of recyclable materials. This alternative is called “organized primary collectors”.
- About 9,600 people are still working in the informal waste sector.
- A fraction of 17% of the total biowaste generated is collected separately from the mixed waste, and sent to biological treatment plants.

The complete definition of the MSW management in the BAU scenario is accomplished by selection of an appropriate technology for the biological treatment. Table 7.4 provides the input for the selection matrix used in the assessment. As mentioned in Section 3.4.3, the weight given to the different aspects in the BAU scenario are:

	Economic	Technical	Environmental
Weight	3	2	1

By multiplying the weight of the respective aspect (3: economic, 2: technical and 1: environmental) with the average result of the technological evaluation (Table 7.4) it is possible to obtain only one aggregated value for each technology (composting, anaerobic digestion) which corresponds to each aspect (economic, technical, environmental). The values corresponding to one technology are added, and the largest value indicates the technology to chose. These results are shown in Table 7.11.

Table 7.11 Selection matrix, biological treatment – BAU scenario

	Economic	**Technical**	**Environmental**	**Total**
Composting	0.67	0.75	0.00	3.5
Anaerobic digestion	0.67	1.00	1.00	**5.0**
Weight	**3**	**2**	**1**	

Consequently, the selected technology for the biological treatment of MSW in the BAU scenario is anaerobic digestion.

Figure 7.2 shows the mass flow diagram for the BAU scenario for the year 2030. Additionally, energy recovery from MSW is achieved with the installation of anaerobic digestion plants to produce about 54,000 Mg/year of biogas, corresponding to 63 GWh of electricity generation. Additionally, LFG is captured and used as an energetic renewable source. In this scenario, 440 million m³/year of landfill gas are recovered, corresponding to the generation of 890 GWh of electricity (Table 7.12).

Table 7.12 Energy recovery from MSW – BAU scenario

	Biogas/landfill gas [Million Nm³/year]	**Electricity generation [GWh]**
Anaerobic digestion	47	63
Landfill gas collected in year 2030	440	890

7.4 MSW Management Scenario: Collective Responsibility

7.4.1 Storyline

This scenario is characterized by high emphasis on social values, instead of the possession of products, as well as by social environmental justice as main goals of public guideline, strong regulation of market activities, large public investment and decoupling of socio-economic development from resource use. Increase of climate change prevention and renewable energy policies has motivated the recovery of energy from waste, and the collection and use of landfill gas as renewable energy source.

The influence of NGOs in the waste area is relevant, in particular encouraging recycling, source separation and acceptance of the informal primary collectors. What was known as “formal recycling” has almost disappeared. On the contrary, thanks to the strong influence of community based organizations and NGOs, the organization and efficiency of the primary collectors has improved noticeably. These community organizations play an important role in collecting recyclable materials and bringing them to store centers strategically located within the MRS. The informal sector has decreased in number, as a result of poverty reduction. The quality of the work (waste separation, processing) carried out by organized primary collectors has increased. They have formed strong groups in several municipalities and work in the collection of materials and their processing. Public investment in environmental campaigns has contributed to the creation of more participation and acceptance of the primary collectors by the civil society.

The technology development is not a priority in this scenario, but a tool used to achieve environmental goals. All landfills comply with the international standards, and collection and treatment of leachate and landfill gas.

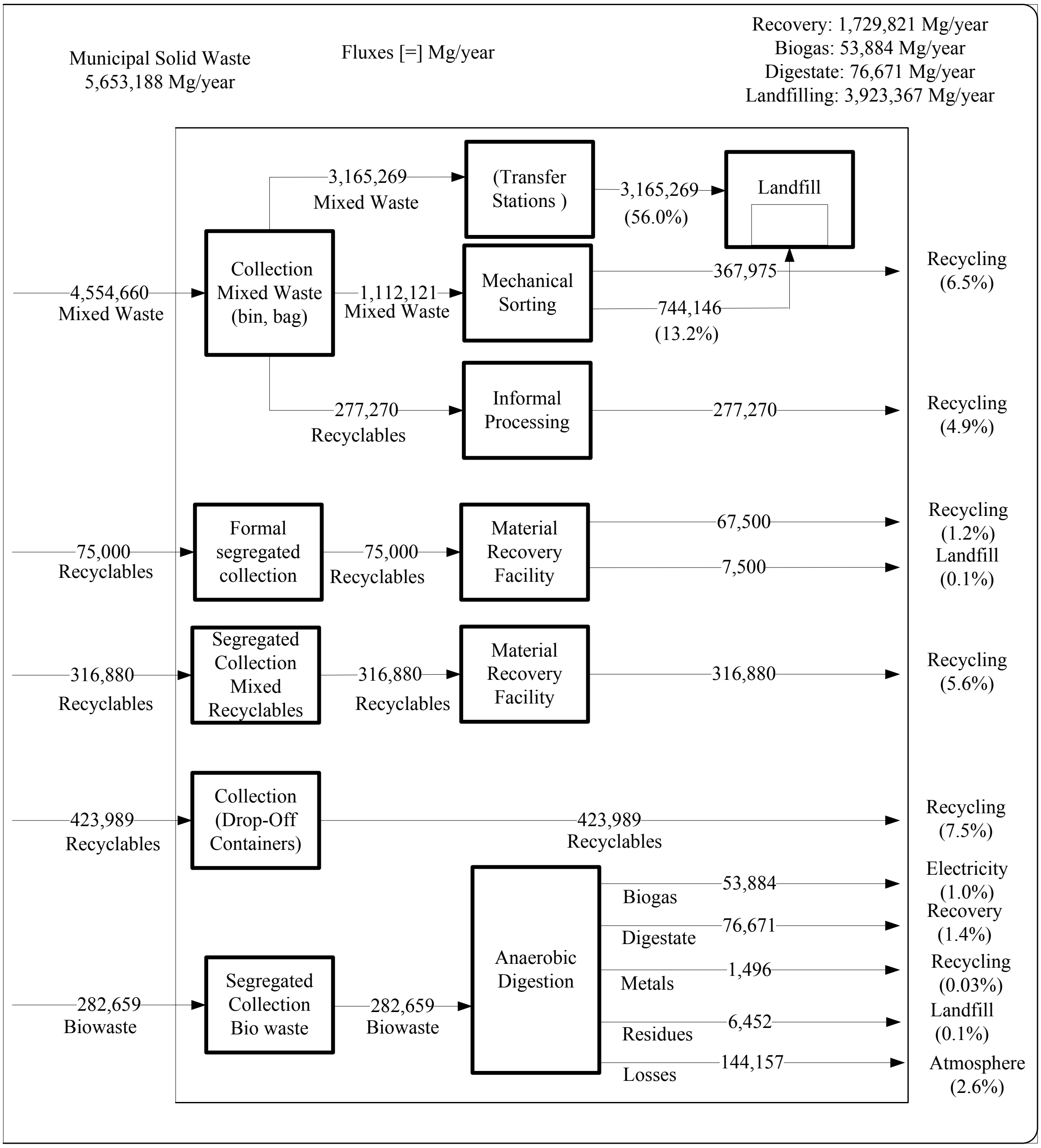


Figure 7.2 Municipal Solid Waste Mass Flow Diagram – BAU scenario year 2030

7.4.2 MSW generated

In this scenario, the flux of MSW produced is calculated as a function of selected parameters, as explained in Section 3.4.2.2. The total waste flow is obtained with the population of the MRS (7.6 million inhabitants for the CR scenario), in addition to the quantity of green and yard waste. These results are shown in Table 7.13.

In the CR scenario, the MSW flux increased from the baseline value (1.1 kg/(person·day)) in 2007 to 1.7 kg/(person·day), resulting in an annual growth rate of 2.3%.

7.4.3 Waste composition

Table 7.14 shows the MSW composition in the CR scenario in the year 2030, calculated as explained in Section 3.4.2.3.

Table 7.13 **MSW flow generation in CR scenario**

Variable		MSW generated (CR)
MSW Flow (M^*)	[Million Mg/year]	4.9
Specific[a] (M)	[kg/(person·day)]	1.7
Specific[b]	[kg/(person·day)]	1.8

a: calculated with Equation (48)
b: corresponding to the total waste generated

Table 7.14 **Composition of MSW – CR scenario**

Waste fraction	Composition [%]
Food waste	25
Yard waste	7
Paper/cardboard	28
Plastics	12
Glass	5
Metals	8
Other	15

7.4.4 Municipal solid waste mass flow

On the basis of storyline and characteristics of the CR scenario, the following waste management measures are implemented:

- A fraction of the mixed waste collected is diverted to mechanical sorting plants, to obtain valuable materials for recycling. The fraction sent to the plant is 20% of the total mixed MSW collected.
- A fraction of the mixed waste collected is diverted to mechanical biological plants to produce alternative refuse fuels and pretreat the waste sent to the landfills. The fraction sent to the plant is 20% of the total mixed MSW collected.
- A fraction of 7.5% of the MSW flow generated is collected through drop-off systems. Only drop-off systems for paper and glass are considered, because of higher participation of citizens in the separation of these materials.
- Organization of the informal workers takes place (“organized primary collectors”). Segregated collection of recyclables is carried out by waste collectors and materials are further processed in improved material recovery facilities.
- About 4,000 people are still working in the informal waste sector.
- A fraction of 25% of the total biowaste generated is collected separately and sent to biological treatment.

The waste management alternatives proposed for this scenario allow diverting almost 60% of the total MSW generated from landfilling. The actual quantity of materials and energy recovered depends on the technologies selected.

To completely define the MSW management of the CR scenario, biological and energy treatment technologies were selected. As mentioned in Section 3.4.3, the weights given to the different aspects in this scenario are:

	Economic	Technical	Environmental
Weight	2	1	3

Following a similar approach than for the selection of biological treatment technologies in the BAU scenario, it is possible to select the biological treatment as well as the waste to energy technologies for the CR scenario.

Table 7.15 Selection matrix, biological treatment – Collective Responsibility scenario

	Environmental	Economic	Technical	Total
Composting	0.00	0.67	0.75	2.1
Anaerobic digestion	1.00	0.67	1.00	**5.3**
Weight	**3**	**2**	**1**	

Table 7.16 Selection matrix for waste to energy technologies – Collective Responsibility scenario

Characteristic	Environmental	Economic	Technical	Total
Incineration (electricity generation)	0.0	1.3	1.2	3.8
MBT biodrying	2.0	2.0	0.7	10.7
MBT AD	1.0	0.7	0.3	4.7
MBT biodrying RDF	3.0	1.3	1.0	**12.7**
Weight	**3**	**2**	**1**	

Based on these results, the selected technology for the biological treatment of MSW in the Collective Responsibility scenario corresponds to anaerobic digestion. For the treatment of the mixed waste arriving at landfills, mechanical biological treatment with production of alternative combustible and anaerobic treatment of the organic fraction is chosen.

Figure 7.3 shows the mass flow diagram for the CR scenario for the year 2030. Additionally, in Table 7.17, values of energy recovery from waste are given. The installation of anaerobic digestion plants together with the anaerobic treatment taking place at the mechanical biological plant allows producing 118,000 Mg/year of biogas, corresponding to 133 GWh of electricity generation. Furthermore, an alternative combustible is obtained and co-combusted in cement plants, which allows an energy recovery of 1,048 GWh. Additionally, LFG is captured and used as an energetic renewable source. A total of 380 million m³/year of landfill gas are recovered, corresponding to a generation of 763 GWh of electricity.

Table 7.17 Energy recovery from MSW – Collective Responsibility scenario

	Biogas/landfill gas [Million Nm³/year]	Electricity generation [GWh]	Alternative fuel [Million Mg]	Thermal recovery [GWh]
Anaerobic digestion	65	88	-	-
Anaerobic digestion in MBT	37	44	-	-
RDF	-	-	265	1,057
Landfill gas collected in year 2030	377	763	-	-

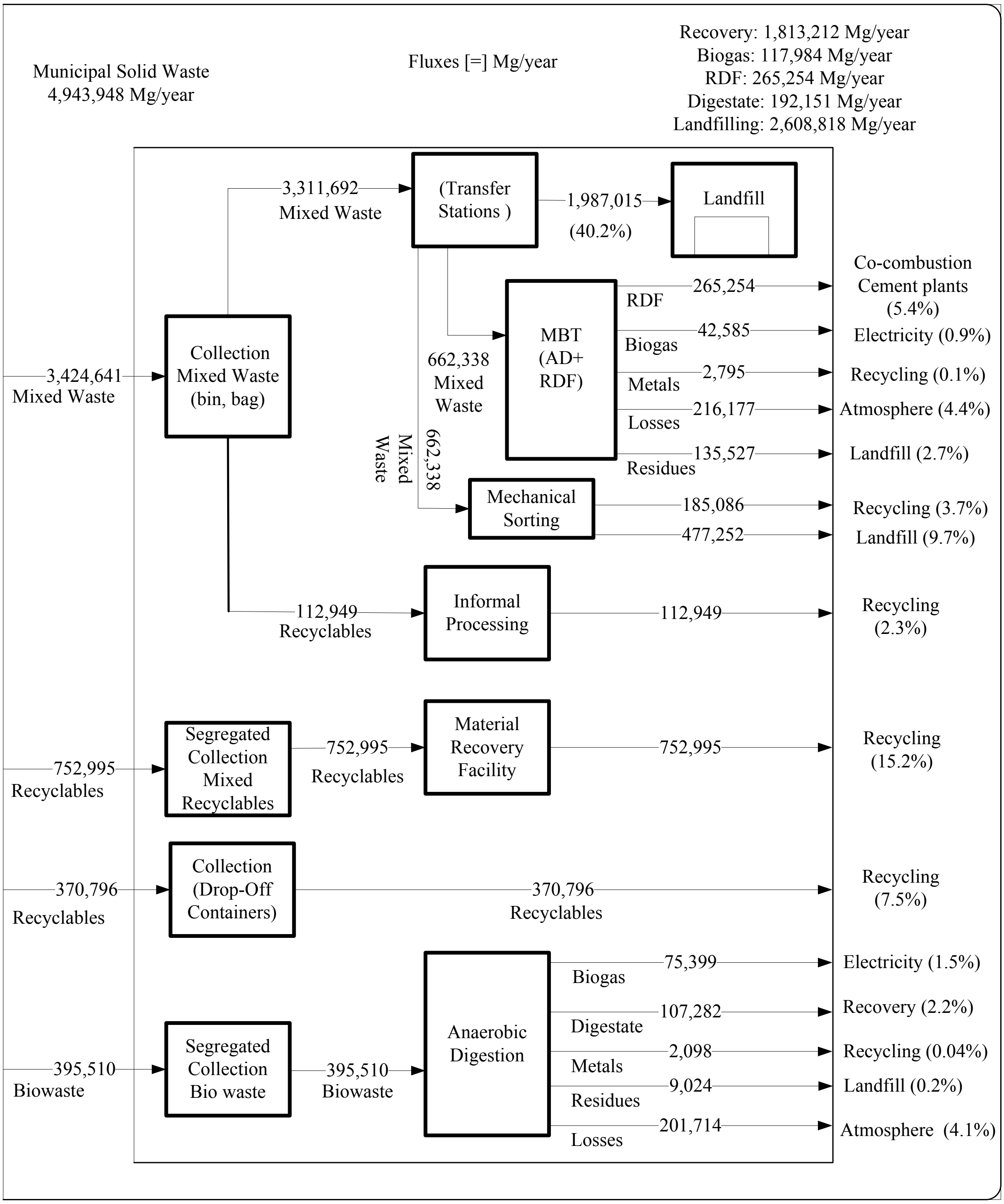


Figure 7.3 Municipal Solid Waste Mass Flow Diagram – CR scenario year 2030

7.5 MSW Management Scenario: Market Individualism

7.5.1 Storyline

This scenario is characterized by a consuming and materialistic culture and increasing individual freedom; markets are the dominant driver in most business, together with the generation of goods and services. Acquisition of ready available products is very common. Environmental laws and regulations in the waste management area are weak or non existent, and influenced by private interests. The driving factor to recover valuable materials and energy from waste is given only by economic profit. Additionally, there is interest in technological development in this scenario. Thus, alternative technologies for the recovery of MSW are developed if costs and profitability are favorable.

Publicly organized recycling systems, including biological treatment are non existent in a significant scale. Recycling takes place only voluntarily, by drop-off systems. The role of the public sector in recycling is inexistent, and there is no concern about working together with the informal sector. Private production companies might show some interest in working together with the informal sector, as a way to recover secondary raw materials at low costs.

7.5.2 MSW generated

In this scenario, the flux of MSW produced was calculated as a function of selected parameters as explained in Section 3.4.2.2. The total waste flow is obtained with the population of the MRS (8.3 million inhabitants in MI scenario), in addition to the quantity of green and yard waste, which was not used in the determination of the specific MSW generation. These results are shown in Table 7.18.

In the MI scenario, MSW flux increased from the baseline value (1.1 kg/(person·day)) in 2007 to 1.9 kg/(person·day), resulting in an annual growth rate of 3.3%.

Table 7.18 **MSW generation in MI scenario**

Variable	MSW generated (*MI*)
Flow (M) [Million Mg/year]	6.1
Specific^a (M^*) [kg/(person·day)]	1.9
Specific^b [kg/(person·day)]	2.0

a: calculated with Equation (48)

b: corresponding to total waste generated

7.5.3 Waste composition

Table 7.19 shows the MSW composition for the MI scenario in the year 2030, obtained following the approach explained in Section 3.4.2.3.

Table 7.19 **Composition of MSW – MI scenario**

Waste fraction	Composition [%]
Food waste	22
Yard waste	6
Paper/cardboard	30
Plastics	13
Glass	5
Metals	8
Other	16

7.5.4 Municipal solid waste mass flow

On the basis of storyline and characteristics of the MI scenario, the following waste management measures are implemented:

- A fraction of the mixed waste collected is diverted to mechanical sorting plants, to recover materials or energy. Because technology and innovation play an important role in this scenario, the waste fraction sent to the plant corresponds to 25% of total collected mixed waste.
- Publicly organized collection of biowaste or recyclables is not introduced.

- A fraction of 3% of the generated MSW flow is collected through drop-off systems.
- The informal waste sector plays an important role in recycling. Because of the larger informality characterizing this scenario, and the lack of organization of the primary collectors, the number of informal workers in 2030 is approximately 19,000.

The waste management alternatives proposed for this scenario allow in principle the diversion from landfilling of almost 25% of the total waste produced. The actual quantity of materials and energy recovered depends on the efficiencies of selected technologies.

In the MI scenario, there is a lack of incentives promoting alternative waste treatments, therefore only mechanical sorting processes, differentiate the MSW flow diagram from the current situation (Figure 7.4). Moreover, a total of 491 million m³/year of landfill gas is collected and used as an energy source (Table 7.20). There are no plants generating biogas in this scenario. The largest recovery rate is achieved through mechanical sorting plants.

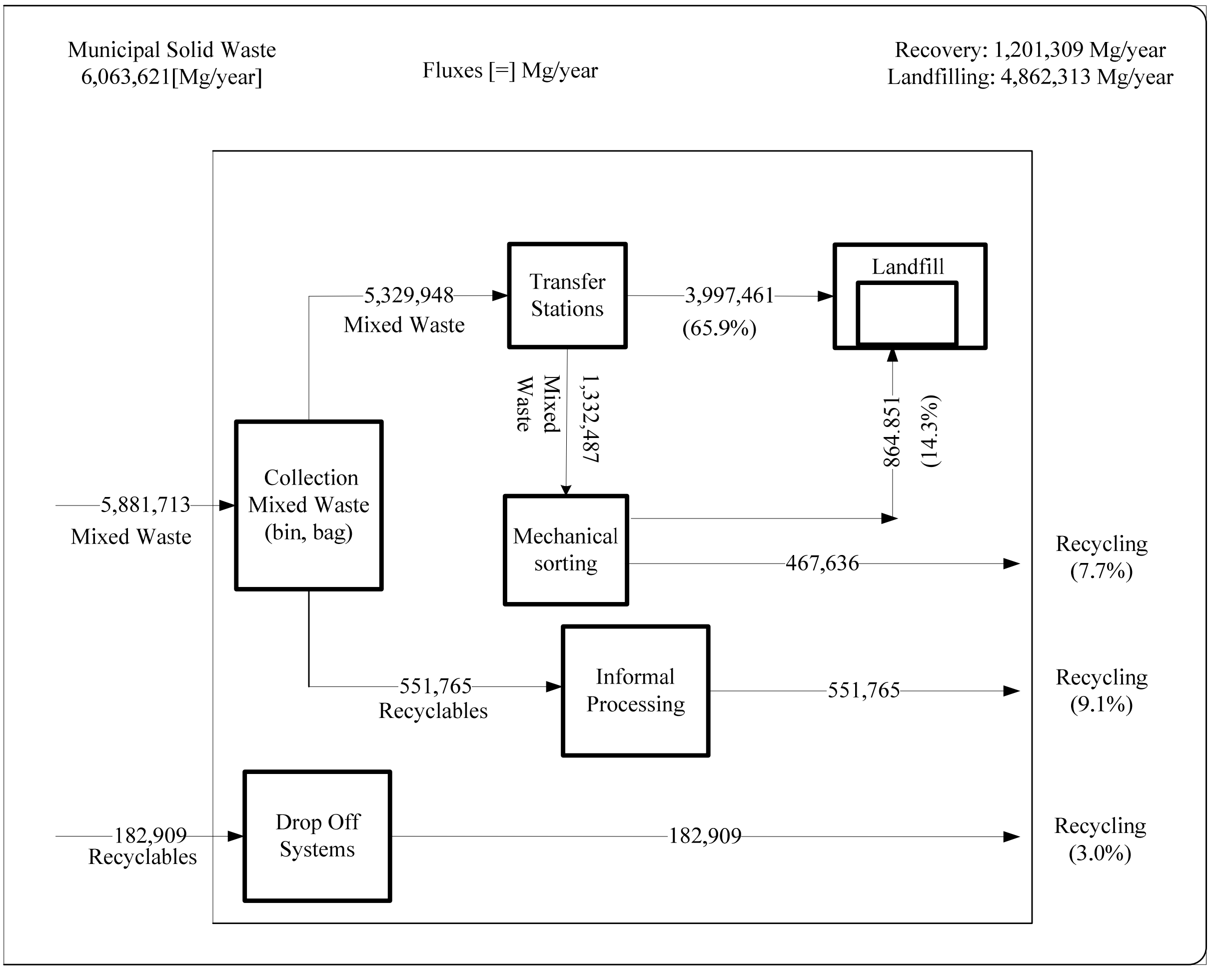


Figure 7.4 Municipal Solid Waste Mass Flow Diagram – MI Scenario year 2030

Table 7.20 Energy recovery from MSW – MI Scenario

	Biogas/landfill gas [Million Nm³/year]	**Electricity generation [GWh]**
Landfill gas collected in year 2030	489	989

7.6 Sustainability Assessment of MSW Management Scenarios

The results of the sustainability assessment for the three scenarios are presented in this Section. The assessment was elaborated on the basis of the selected indicators of sustainability given in Chapter 5.

7.6.1 Flux of municipal solid waste

As mentioned in Chapter 5, a sustainability goal is to maintain the waste flux below 1.6 kg/(person·day). In the BAU and the MI scenarios this limit value is exceed between the year 2024 and 2025 (Figure 7.5). In the CR scenario, the value is exceed in 2029. In the CR scenario, waste flux is not only a function of economic development, however the results obtained suggest that policy targets should focus more strongly in the decoupling of waste generation from economic growth. This affirmation is also valid for the BAU and the MI scenarios, where the waste flux goes above the limited suggested even earlier than in the CR scenario.

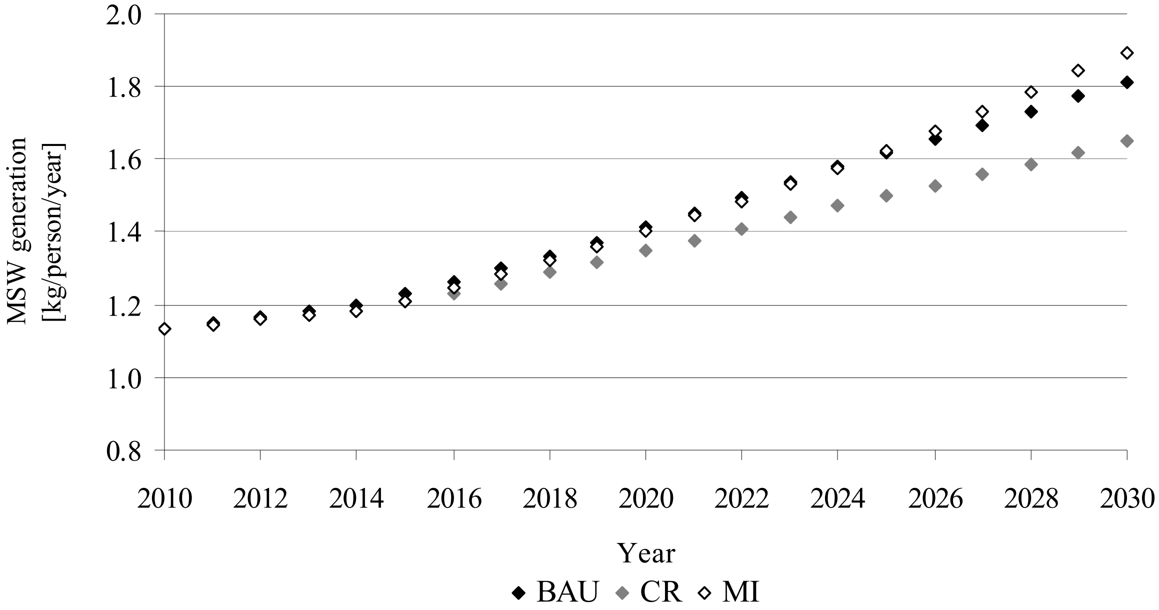


Figure 7.5 Comparison of MSW flux generation, different scenarios in the MRS

As mentioned above, the highest MSW generation flux is obtained in the MI scenario, resulting from a high urbanization process, together with a materialistic and consumption culture and lack of environmental awareness. The specific waste generated in the BAU scenario does not differ largely from the waste produced in the MI scenario between the years 2010 and 2025, which is attributable to the fact that the elements affecting the MSW generated (Equation 48) do not change noticeably between these two scenarios in this period of time. Moreover, the impact of these factors (GDP, urban population, household size, household income, years of schooling) on waste generation seems to have a compensating effect on the values obtained for the MI scenario until 2025. After this year, the MSW generation increases further, due to a larger increase of GDP and the reduction of the household size in the MI scenario with respect to the BAU scenario.

The value of waste generation, obtained in the CR scenario for 2030 is primarily the result of a noticeably low urban population in comparison to the BAU scenario, additionally to a larger household size which also impacts significantly on the amount of waste generated.

7.6.2 Waste fraction recovered as material or energy

The recovery rate includes substance flows that are used as secondary raw materials and materials used for energy recovery. It is observed (Figure 7.6), that from the year 2013 on, the recovery rate in the CR scenario increases faster than in the BAU and the MI scenarios, reaching a rate of 43% in 2030. The recovery rate growth in the BAU scenario is slower, reaching a value of 31% in the year 2030. The lowest recovery rate is obtained in the MI scenario, with a recovering rate of 20%.

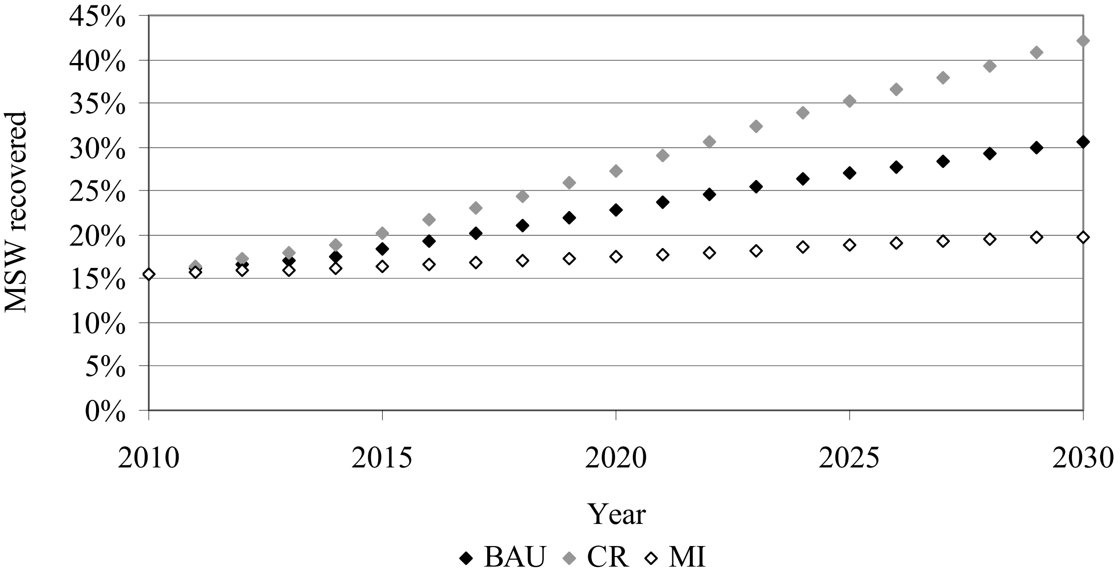
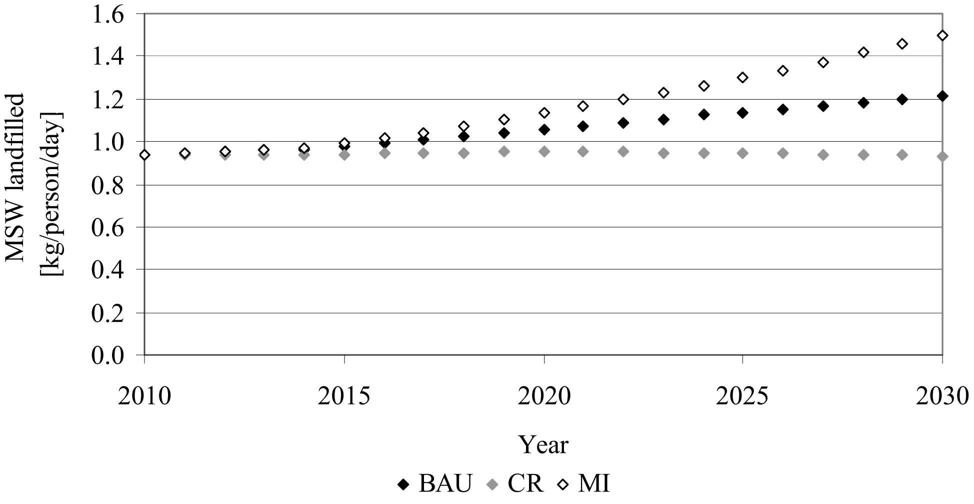


Figure 7.6 Comparison of MSW recovering rate, different scenarios in the MRS

The results shown in Figure 7.6 are closely linked with those of Figure 7.7, where the quantity of MSW landfilled per capita is presented. It is interesting to notice, that in the BAU and in the MI scenarios, the flux of waste deposited in landfills increases up to 29% and 60% respectively. It is clear that if the amount of waste deposited in landfills in per capita terms increases, it is difficult to increase at the same time the amount of waste recovered. In the CR scenario, a reduction of one percent in the specific amount of waste sent to final disposal is achieved; therefore, even with an increase in population, it is possible to decrease the quantity of waste arriving at landfills, and in consequence it is reasonable to expect an improvement in the total recovery rate.

The sustainable recovery target proposed is 36% of the total MSW generated, a value that is only reached (and even exceeded) in the CR scenario. In this case, the recovery rate of 43% is attained through recycling, through public – private partnerships (as in the case of drop-off systems), private investment (as in the case of sorting plants at transfer stations), and organization of the informal waste workers. In addition, there is a contribution to sustainability by the recovery of biowaste and energy from biogas and refused derived fuels (RDF) (Figure 7.8). It should be noted, that informal recycling still plays a role in this scenario, contributing with almost 8% of the total waste recycled.

In the BAU scenario, the recovery rate of 31% (Figure 7.8) is achieved through improvements in the collection of secondary raw materials. Recovery strategies are introduced in a lower scale than in the CR scenario, due to lack of environmental guiding principles and policies, and large private influence on decision making. In the BAU scenario, the informal sector contributes with 19% to the total material recycling. Energy is recovered from LFG and biogas produced in anaerobic digestion plants.



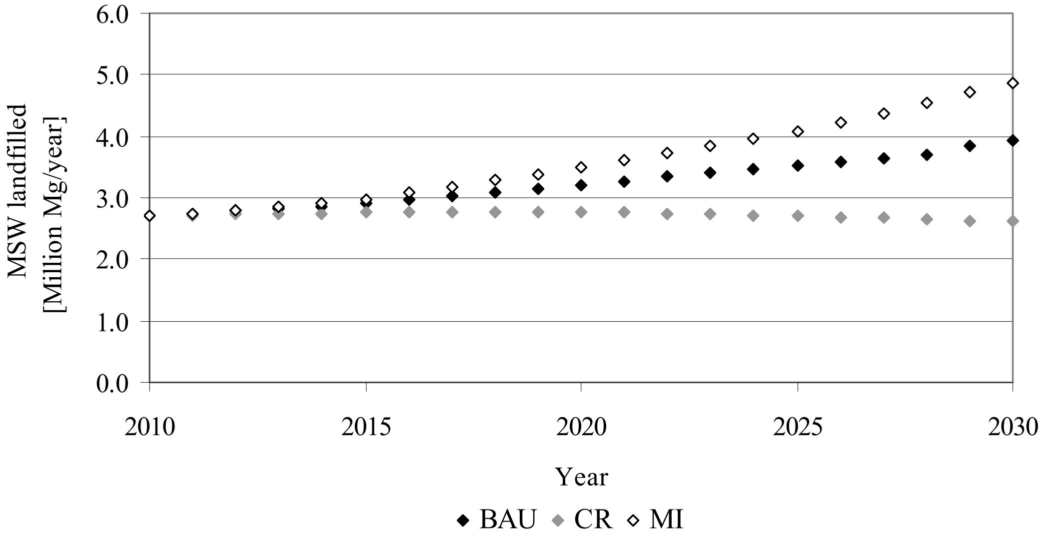


Figure 7.7 Comparison of MSW landfilled, different scenarios in the MRS

As mentioned above, the lowest recovery rate corresponds to the MI scenario that considers the recovery of materials through sorting plants installed at transfer stations and the participation of the informal waste workers, who contribute with 46% to the total recycling rate (Figure 7.8).

Figure 7.9 shows the results of the recovery rate for these three scenarios, assuming that the mechanical sorting plants, whose current function is to recover materials for recycling, would change this function to recover materials for energy generation (by production of RDF), in addition to the recovery of glass and metals. Thus, in the BAU and MI scenarios, a new contribution to recovery exists, namely by co-combustion of RDF in cement plants, and causing in the CR scenario, the production of RDF to be larger than before. This change brings about an increase in the recovery rate to 33%, 44% and 22% in the BAU, CR and in the MI scenarios, respectively.

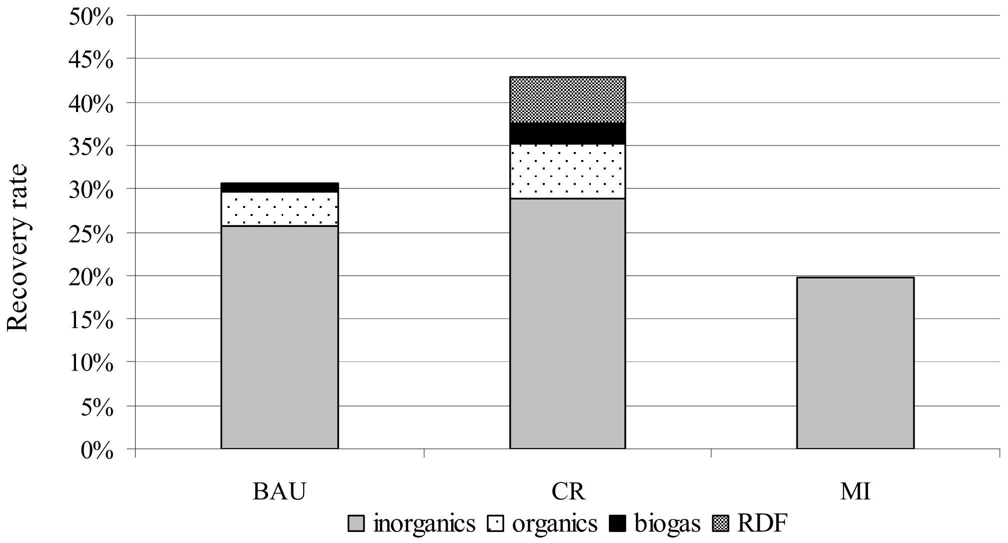


Figure 7.8 Recovery rate as materials or energy in the three scenarios – 2030

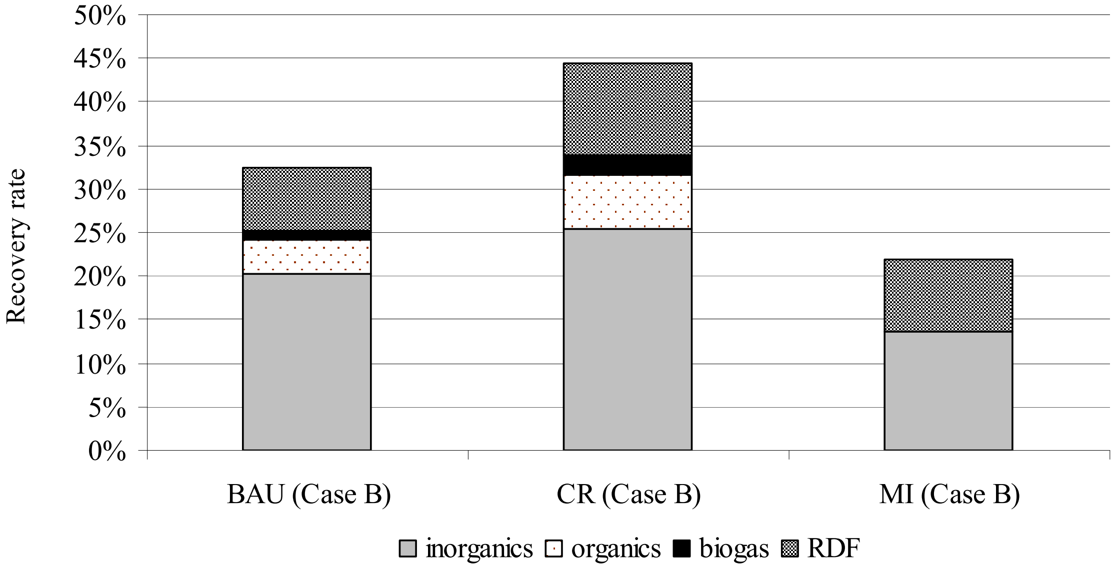


Figure 7.9 Recovery rate as material or energy with production of RDF – 2030

7.6.3 Amount of mixed waste pretreated to reduce organic carbon content in relation to total mixed waste

It was established as sustainability target (Chapter 5), that at least 50% of the mixed MSW collected should undergo pre-treatment before final disposal in sanitary landfills.

In the BAU and the MI scenarios there is no pre-treatment of mixed collected waste, therefore the corresponding value is 0%. In these scenarios, there is lack of incentives for the implementation of waste pre-treatment, in particular regarding environmental protection and climate change. In the MI scenario, lack of waste pre-treatment is also a consequence of the low economic profitability of such practices.

In the CR scenario, 18% of the mixed collected MSW goes through pre-treatment processes before landfilling. This rate is achieved through to public health and environmental protection policies, and the promotion of energy recovery from waste, which at the same time encourages waste pre-treatment practices. Even though there is a significant improvement with respect to the pre-treatment fraction in 2007, the rate achieved in 2030 is still below the desired target. Therefore, impacts of depositing waste in landfills without previous treatment will have in this scenario a negative effect on the environment and on climate change.

It is feasible to think, that in the BAU scenario environmental protection and climate change prevention policies could encourage pre-treatment technologies. It was estimated that 17% of the mixed collected waste could undergo pre-treatment if a biological step is added to the already existent mechanical treatment plants.

7.6.4 Greenhouse gases emitted during waste management

Generated and avoided GHG emissions occurring during waste treatment are shown in Figure 7.10. The largest contribution to GWP is given by methane emissions from landfill sites in the three scenarios, as a consequence of the anaerobic decomposition of the biogenic fraction of the waste deposited in landfills. The improvement in efficiency of landfill gas collection to 55%, contributes to the reduction of these emissions in all three cases. The landfill gas collected is used as a renewable energy source in electricity generation, which also contributes to GHG emissions reduction (avoided emissions associated with combustion of fossil fuels).

The net GWP obtained from recycling indicates that emissions associated with production of goods, by using raw materials are larger than if secondary raw materials are utilized. Finally, in the CR scenario, substitution of fossil fuels by alternative combustibles in cement kilns also contributes to avoid GHG emissions.

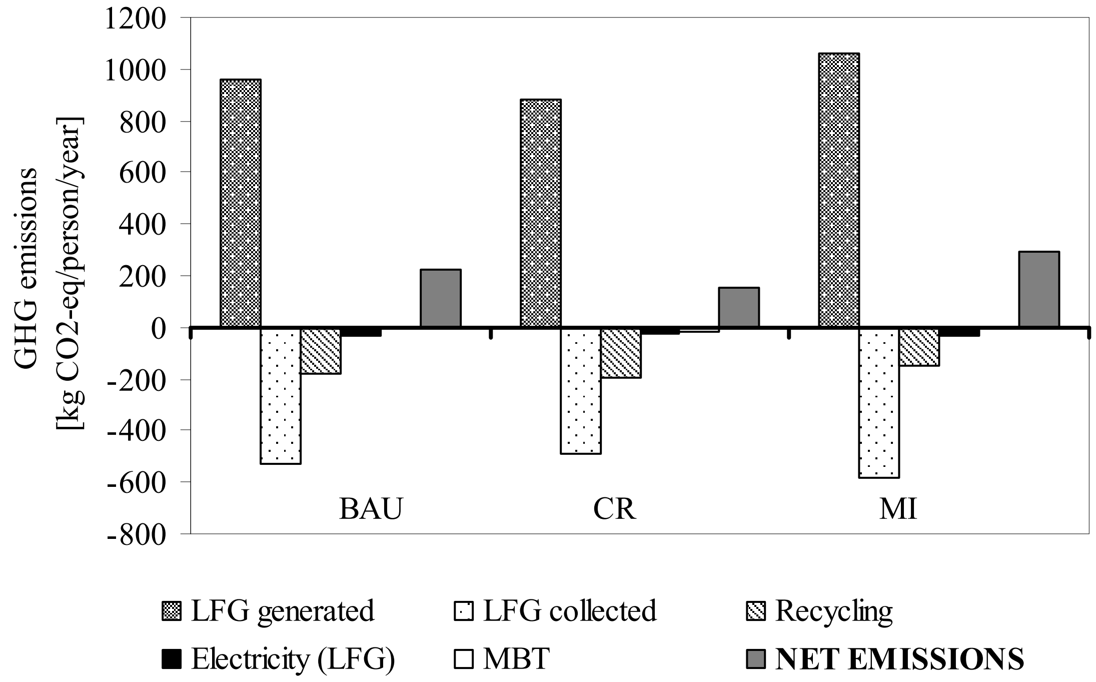


Figure 7.10 Global warming potential of MSW management scenarios in MRS, 2030

The net GWP is highest in the MI scenario, with 295 kg $CO_{2\text{-eq}}$/(person·year). This value results as a consequence of the large amount of waste deposited in landfill sites without previous treatment, in addition to low recycling rates. The GWP of the BAU and the CR scenarios are lower, with 224 and 155 kg $CO_{2\text{-eq}}$/(person·year), respectively. These values are the result of lower amounts of MSW deposited in landfills, achieved by improving the collection of biowaste and recyclable materials, in both cases. In the CR scenario, the additional increase of mixed waste pretreated to 18% also affects the GWP indicator positively. Nevertheless the target proposed for 2030 of 71 kg CO_{2eq}/(person·year) is not achieved in any scenario.

If the landfill gas is not used to produce electricity, but only collected and flared, the net GWP balance in per capita terms increases 13%, 17% and 11% in the BAU, CR and MI scenarios respectively. Therefore, the substitution of fossil fuels by landfill gas in electricity generation plays a significant role in reduction of GWP, in particular in the CR scenario.

Figure 7.11 illustrates the global warming potential development between 2010 and 2030 for the three scenarios. As observed, a maximum value is reached around the year 2017 for the CR scenario, 2019 for the BAU scenario and 2022 for the MI scenario, decreasing afterwards. This decline is attributed in the first place, to improvements in collection efficiency of landfill gas, and associated electricity generation. Additionally, it is also connected with larger quantities of recycling and recovery, which diverts waste from landfilling. Moreover, the segregated collection of biowaste takes place in the BAU and the CR scenarios, reducing the biogenic fraction of the waste arriving at landfills, which in turns reduces the methane emissions.

The trends observed in Figure 7.11 are encouraging, because they show a reduction of GWP. However, given that efficiencies of landfill gas collection above 55% are difficult to achieve, other waste management strategies should be implemented in order to achieve the target of 71 kg $CO_{2\text{-eq}}$/(person·year).

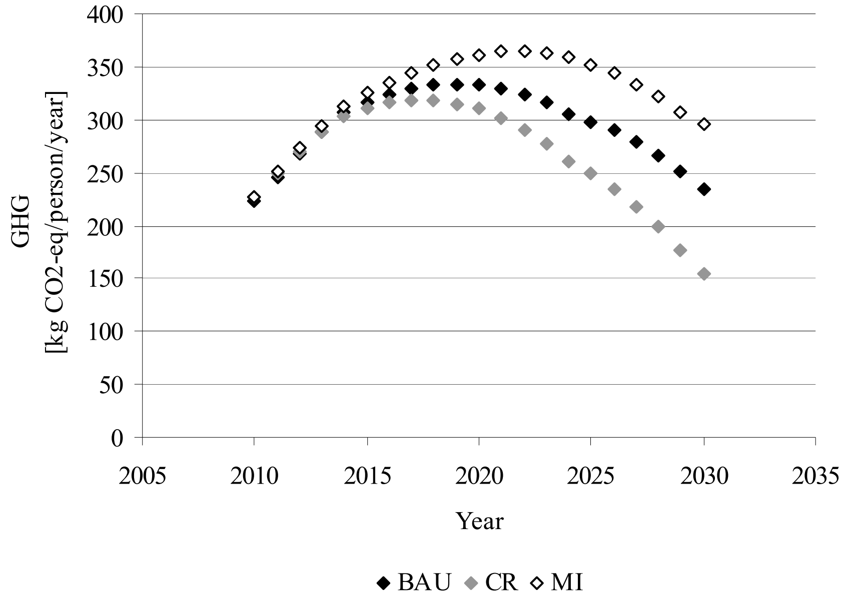


Figure 7.11 Comparison of global warming potential evolution of MSW management, different scenarios in the MRS

7.6.5 Remaining life time of adequate landfill facilities

The landfill capacity is especially important where space is scarce, and it can be used as a measure for resources conservation.

Figure 7.12 shows the total MSW deposited in the landfills of Santiago de Chile until the year 2030. According to the Environmental Impact Assessment of the landfills located in the MRS, these sites have a design capacity of about 172 million tons. As observed, this limit is not reached in any scenario in 2030. However, 55% of this capacity is reached in the BAU scenario, 48% in the CR scenario and 59% in the MI scenario, all values for 2030.

Assuming that the respective landfilling trends are maintained in each scenario, then the landfill capacity are reached around 2046, 2065 and 2041 for the BAU, the CR and the MI scenarios respectively. These results are on one side a consequence of the population increase in each scenario, in addition to the flux of MSW landfilled (Figure 7.7).

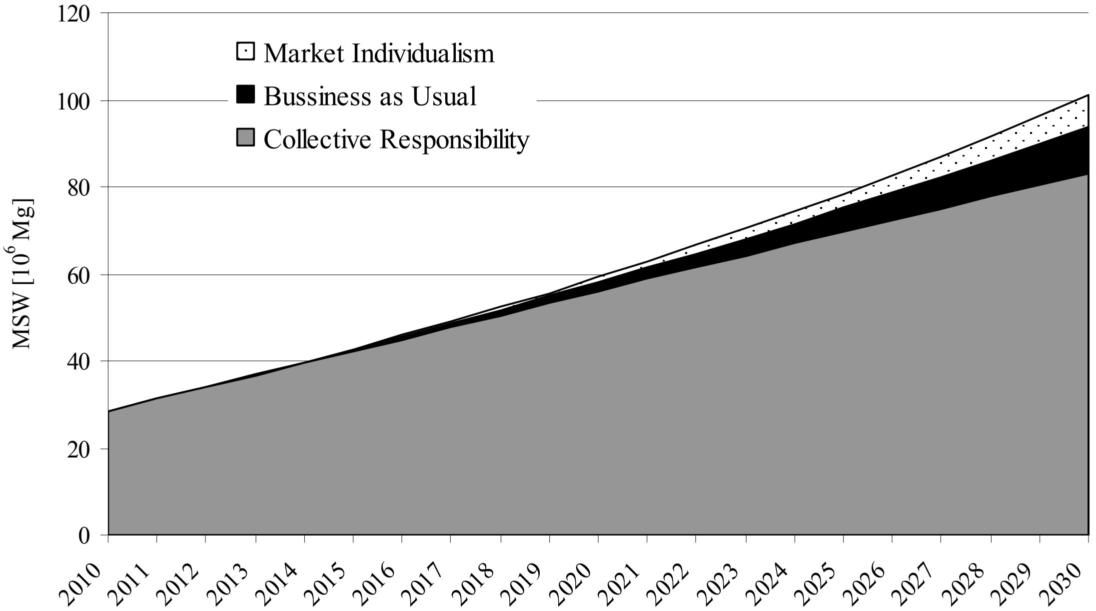


Figure 7.12 Comparison of landfill capacity for different MSW management scenarios in the MRS

7.6.6 Municipal solid waste management costs

Figure 7.13 illustrates the share of MSW management costs in the three scenarios. These costs were roughly compiled in three categories. *Collection costs*, comprising expenditures of collection and transportation of mixed and segregated waste. The production costs of biological treatment, mechanical biological treatment and recycling were categorized as *waste treatment costs* and finally *landfilling costs* include costs of transfer stations and final disposal at landfill sites, as they are currently calculated, namely without post closure costs.

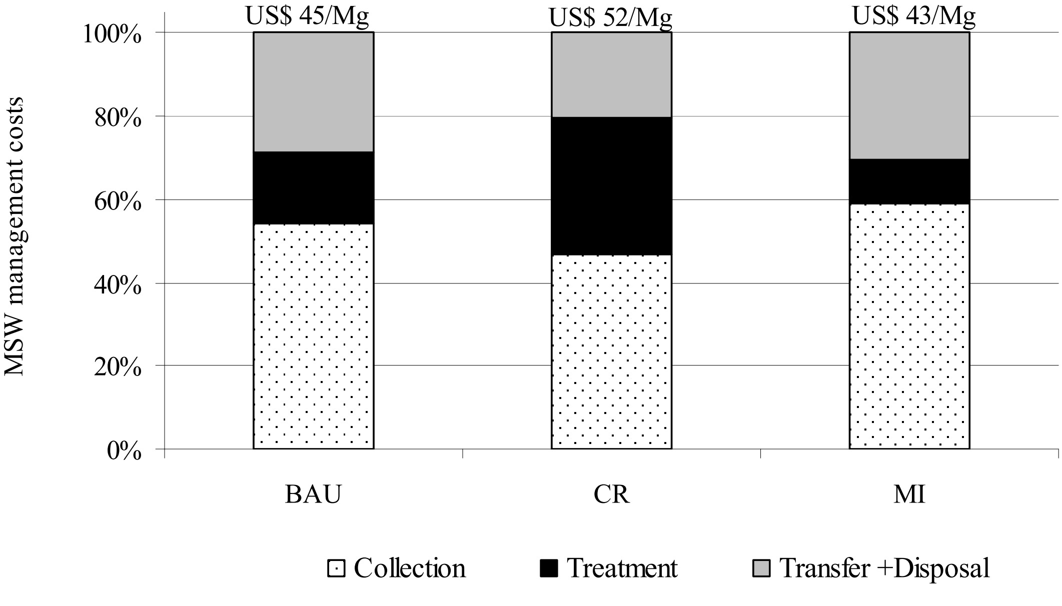


Figure 7.13 Share of MSW management costs in the three scenarios

Collection costs correspond to approximately 60% of the total expenditures in the MI scenario, whereas treatment costs represent only 11% of the total. This result is the consequence of the relatively simple waste management of this scenario, largely based on disposal at landfill sites without alternative treatment technologies. The treatment costs in this scenario correspond to mechanical sorting of valuable materials taking place at transfer stations.

In the CR scenario, waste treatment costs represent 34% of the total expenses. This fact is not surprising, because of the implementation of anaerobic digestion plants, improved collection of recyclable materials and energy recovery considered in this scenario. The landfilling costs share reduces to 20% (landfilling costs corresponded to 36% of the total waste management costs in 2007). In contrast, landfilling costs in the BAU and in the MI scenarios correspond to 28% and 30% of the total costs in 2030. Nevertheless, in the BAU, alternative waste treatment technologies are implemented, therefore the fraction of the total costs spent on treatment reaches 19%, being larger than in the MI.

The total expenditure for MSW management and the fraction of these costs in relation to the gross domestic product of Santiago de Chile are depicted in Figure 7.14. As observed, the total costs increase in all cases. The highest total waste management costs are found in the MI scenario. This is principally a consequence of the total increase in waste generation. On the contrary, the lowest total costs are found in the CR scenario, the increase observed here is a consequence of the moderate increase in the total waste generation and to the implementation of new waste management treatments technologies, which rise specific costs. The costs increase observed in the BAU scenario are a consequence of the total waste flows rise, and of the implementation of new treatment technologies.

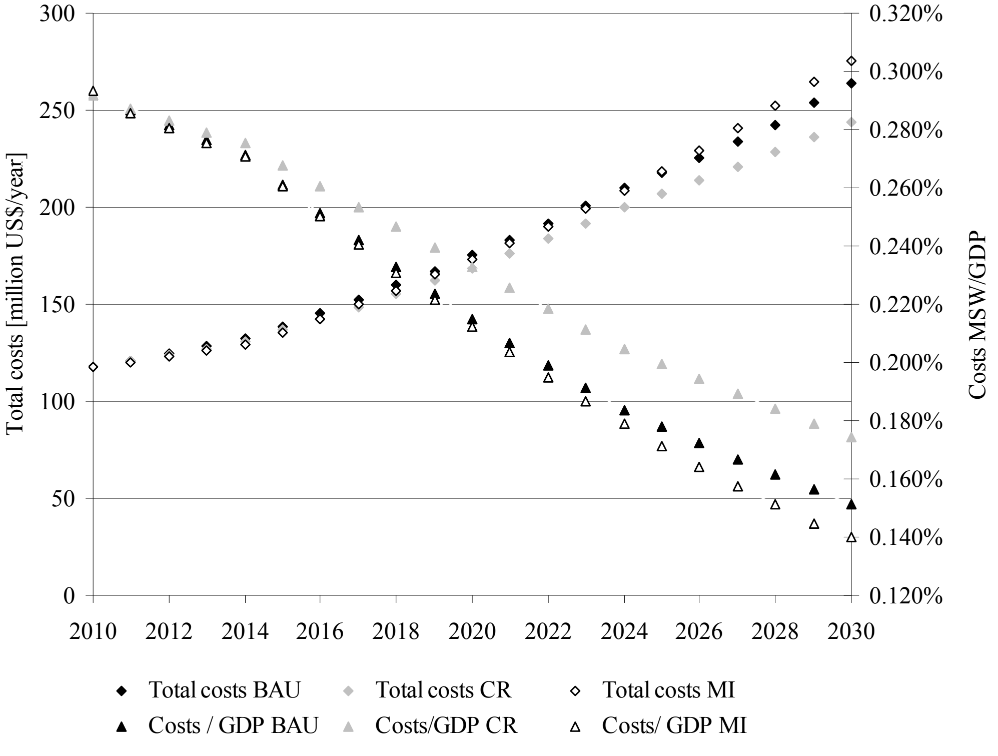


Figure 7.14 Comparison of MSW management costs, different scenarios in MRS

On the contrary to the results found in total costs, the fraction of GDP spent on MSW management decreases in all scenarios. The GDP of a region gives a rough estimation of its potential to select certain waste management treatments (Brunner and Fellner 2007). Usually, this value varies between 0.2% and 0.5%, but as observed in Figure 7.14, this indicator is lower than 0.2% in all cases. The economic development of Chile for the three scenarios suggests that the share of GDP spent on MSW management should increase, allowing a proper management of the MSW flow produced. Larger expenditures in MSW management could reflect the expected enhancement of technological standards and establishment of appropriate solid waste treatment technologies, which contribute to achieve the objectives of sustainable waste management. The fraction of GDP spent on MSW management proposed as target is 0.3% (Chapter 5), which expressed in per capita terms allows the comparison of this value between scenarios. These targets, as well as the costs per ton and cost per person for every scenario are shown in Table 7.21.

Table 7.21 Costs of MSW management in the three scenarios

		BAU	**CR**	**MI**
Target [US$/person] corresponding to 0.3% of GDP		59	59	61
Total Costs	[Million US$/year]	264	244	275
Costs per capita	[US$/person]	33	32	33
Costs per ton of MSW collected	[US$/Mg]	45	52	43
Costs/GDP	[%]	0.15	0.17	0.14

As observed in Table 7.21, the target is not achieved in any scenario. The average costs of MSW management for the year 2007 in Santiago de Chile were used for landfills and transfer stations. It is however expected, that in order to improve collection and treatment of leachates and landfill gas on these sites, these costs would also increase. It is feasible that the total MSW management costs for the year 2030 are underestimated, but they serve as comparison between scenarios.

Even though the costs per capita are similar in each scenario, the costs per ton vary in a more noticeable way. Special attention is given to the costs in the CR scenario, which reaches a value of US$ 52 per ton of collected waste. This larger value is attributed to the implementation of new waste treatment processes, which introduce additional costs components. It would also be expected, that the economic development of Chile and its entering into the OECD would force introduction of stricter emissions limits, which would as well increase MSW management costs.

7.6.7 Income level of primary collectors in relation to average household income

On the basis of the model described in Chapter 6, organization of informal primary collectors was taken into account in the BAU and the CR scenarios.

Figure 7.15 shows the income of *organized* primary collectors and the income of *informal* primary collectors in relation to the income of one individual per household. In the CR scenario, the target proposed for the income of organized primary collectors in relation to the individual household income of Santiago de Chile in 2030 is achieved and exceeded (158%). In the CR scenario, more than 70% of the informal workers are organized. In the BAU scenario, the organized collectors' profits reach a value 13% higher than the individual household. Nevertheless, a large fraction of the primary collectors work still in the informal sector (64%). In the MI scenario organization of primary collectors do not takes place.

In relation to the earnings of primary collectors that are not organized (informal workers), the largest value is obtained in the CR scenario and the lowest in the MI scenario. The differences obtained in the estimation of this indicator are a consequence of the differences in the individual household incomes which differ in every scenario, being US$ 696 per person and month in the BAU scenario, US$ 637 per person and month in the CR scenario and US$719 per person and month in the MI[15] scenario.

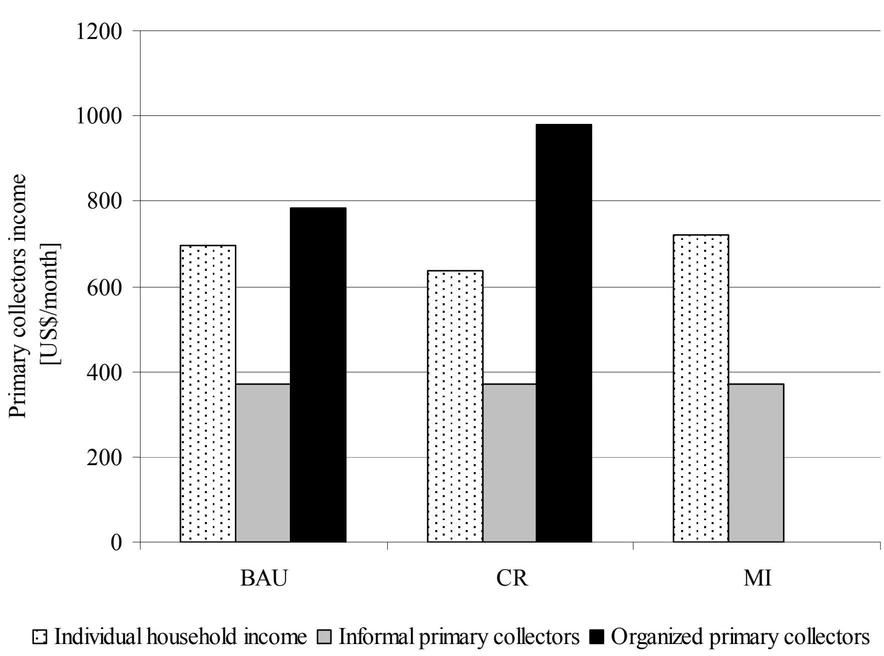


Figure 7.15 Income of informal and organized waste workers, in scenarios in MRS

7.6.8 Distance to target of indicators of sustainability

Table 7.22 summarizes the results of the sustainability evaluation for the current situation and for the future scenarios of MSW management. In Figure 7.16 the indicators' values were translated to percentage, to illustrate their distance to the target, the sustainability target considered to be 100% in the graph. A larger distance to this target means larges sustainability deficits. Figure 7.16 (above) shows those indicators where it is not desirable to have a value higher than 100% (i.e. waste generated, greenhouse gas emissions, landfill capacity). Figure 7.16 (below) shows those indicators where on the contrary, values lower than 100% are not desired (i.e. waste pretreated, waste recovered, costs of waste management in relation to GDP and income of primary collectors).

The largest distance to the target and therefore largest sustainability deficit in all the scenarios is obtained for the GHG associated with waste management.

Table 7.22 Sustainability indicators- Current situation and future scenarios

Indicator	2007	Target	BAU	CR	MI
Specific waste generated [kg/(person·day)]	1.2	1.6	1.8	1.7	1.9
Amount of mixed waste pretreated to reduce organic carbon content in relation to total mixed waste [%]	0	50	0	18	0
Greenhouse gases emitted during waste management [kg CO_{2eq}/(person·year)]	143	71	224	155	295
Waste fraction recovered as material or energy [%]	14	36	31	43	20
Income level of primary collectors in relation to individual household income [%]	76	100	75	128	51
Costs of MSW in relation to GDP [%]	0.22	0.30	0.15	0.17	0.14

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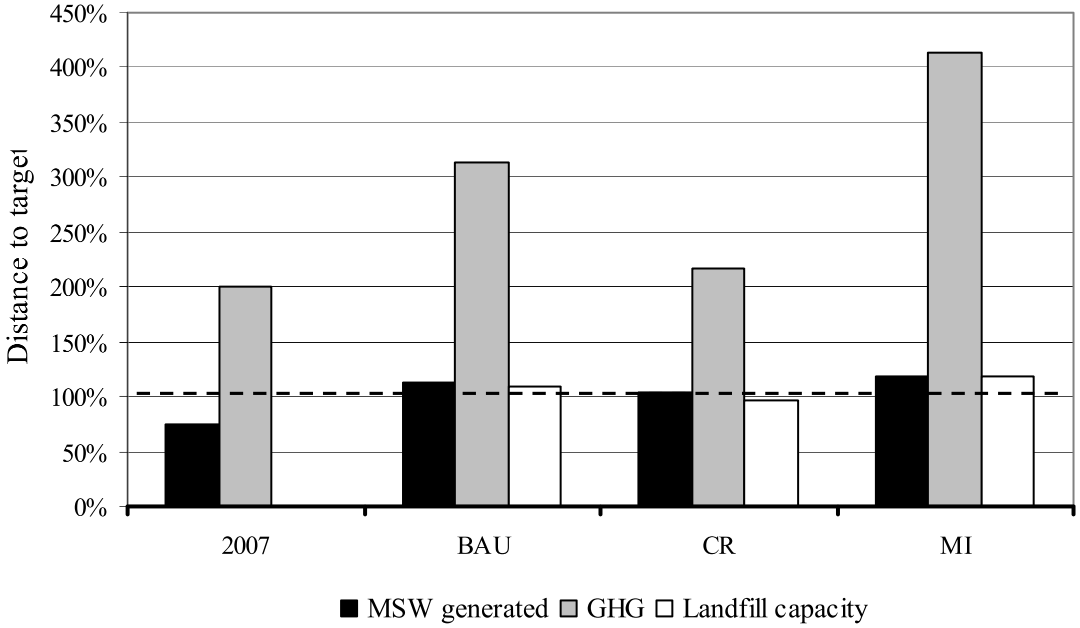
[15] Household incomes were provided within the RHM Project, and are independent of the results presented here.



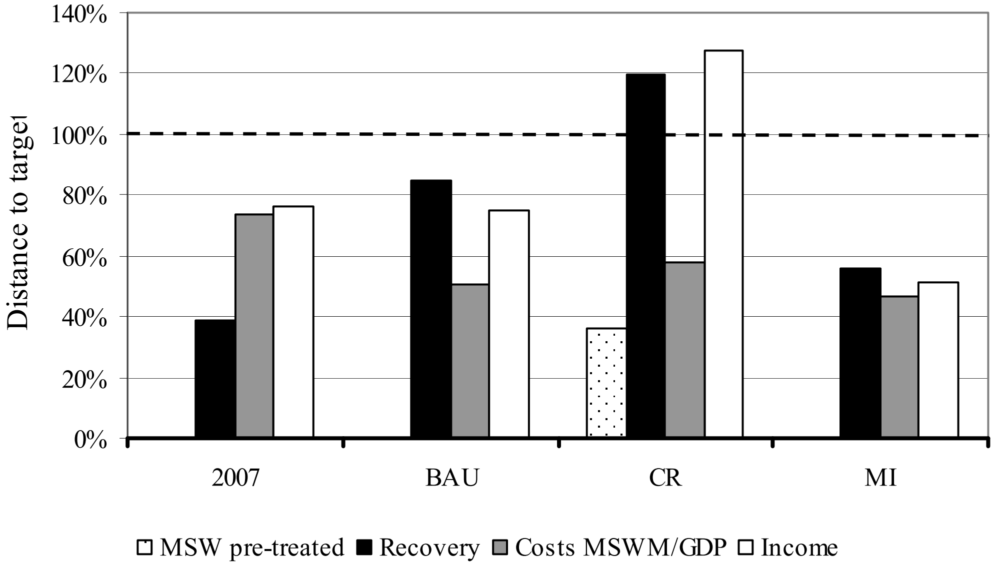


Figure 7.16 Indicators of sustainability in scenarios of MSW management

In the BAU scenario, the waste generation and landfill capacity have exceeded the maximum limits proposed, therefore endangering sustainability. This excess suggests that early waste prevention measures are needed to decrease the rely on landfill sites, and it provides a warning about construction of new landfills for the future, as well as other waste treatment facilities. A sufficient quantity of waste management infrastructure is required in this scenario to handle the solid waste generated. Another critical deficit is related to the quantity of waste pretreated, which does not show improvements in relation to 2007, causing negative effects on human health and the environment, through the direct deposition of waste in landfill. In addition, the expenditures on MSW management as fraction of GDP show a reduction in relation with the value in 2007, which do not correlate with the considered economic development of Santiago de Chile. A low value of this indicator reveals that the economic potential for investments in the waste management field is not being used. Recovery rates in the BAU scenario are larger than in 2007, indicating a positive trend in resource management efficiency. Another improvement is related with the organization of primary collectors, bringing as consequence a larger income for this group of people.

The most encouraging results are obtained in the CR scenario, whose most critical deficit is associated with the GHG emissions. Even though, the sustainability target is not reached in 2030, its value has only increased 8% in relation to the corresponding value for 2007. In comparison, the increment in the BAU and in the MI scenarios are 57% and 106%, respectively. The flux of MSW generated has exceeded the maximum target by 3%, but the landfill capacity limit established is not yet reached in 2030, providing some time for the construction of waste treatment sites and final disposal infrastructure. Another sustainability deficit is presented in terms of the fraction of GDP spent on MSW management, which indicates that the economic potential that could be used in provision of waste management treatment and services is still low. Pre-treatment of MSW is still scarce, but it has noticeably improved in comparison to the situation for 2007, indicating a positive tendency which should be kept. Other important developments in relation to the situation in 2007 are given by the recovery rate and the incomes of the primary collectors, values that have not only reached the targets, but improved them.

The MI scenario shows several deficits of sustainability, the most critical being the quantity of GHG emissions associated to MSW management. Additional deficits are observed in the flux of MSW generated, which exceed the limit proposed by 18%. The large increase in waste generated exerts heavy pressures in the whole MSW management system. This pressure is of particular importance at landfills sites, due to lack of other waste management alternatives. Therefore, the consideration of construction of new landfill sites should take place in due course, in order to handle the total quantities of waste produced. Another significant deficit is given by quantities of pretreated waste, which do not show any improvement in comparison to the situation for 2007, therefore negative effects of direct waste landfilling have still an impact on the environment and public health. Furthermore, the share of GDP spent on MSW management is, as in the other two scenarios, below the desired target. Recovery rates show only a slight improvement in comparison to the current situation; therefore the need for implementation of other recovery strategies is present, if sustainability targets are to be reached. Finally, the income of primary collectors deteriorates dramatically, in comparison to 2007 putting in jeopardy the possibility of this group of people to secure their own subsistence.

Summarizing, stronger strategies to increase recycling and recovery are needed, in particular in the BAU and the MI scenarios. These strategies could rely on the establishment on systems for the separate collection of biowaste, whose share in the waste composition in the three scenarios is still high. Strategies to increase energetic utilization of MSW are also required.

7.7 Sensitivity Analysis

Sensitivity analysis is a systematic procedure, which allows to estimate the effects of chosen methods and input data on the outcome of a study (ISO 1998). Sensitivity analysis are used to acquire better understanding of the model and to gain insight into which assumptions are critical, affecting choices and helping to build confidence in the model by studying the uncertainties that are often associated with its parameters.

In the present research, the sensitivity analysis involves the variation of different input values to test changes on the corresponding output variables. Those quantitative variables characterizing the framework scenarios, provided within the RHM Project, were kept constant (i.e. economic development, urban population, household income, etc.) because changes on these variables would affect the overall characteristic of the framework scenarios and therefore its intrinsic logic.

The first variable analyzed was the MSW flux generation in the CR and the MI scenarios, by varying parameter *a* to *d* in Equation (48). It was tested how the MSW flux generation varies when one of the parameters *a* to *d* was not taken into consideration, in the determination of the MSW flux. Additionally, it was also analyzed what happens if the economic development in the only parameter used to influence the MSW generated (none of the parameter *a* to *d* were considered).

For the CR scenario, the most sensitive parameters in the determination of the MSW flux are urban population and household size (Table 7.23). Without consideration of these parameters, the MSW generation flux in this scenario would have been larger than the value used in the calculations. In the MI scenario, the most sensitive parameters in the determination of MSW flux are the household income and the household size. But these two parameters show an opposite effect between each other. The MSW flux would have resulted in a larger value without considering the household income in the calculation, because the household income in the MI scenario is rather low, therefore contributing with lower MSW generation rates. On the other hand, if the household size is not considered in the calculations a decrease in the waste generation value occurs.

Table 7.23 Sensitivity of selected parameters on MSW generated (CR and MI scenarios)

	CR [kg/(person·day)]	Variation [%]	MI [kg/(person·day)]	Variation [%]
Current value	1.65		1.89	
Household income out	1.68	1.9	1.95	2.9
Urbanization out	1.69	2.5	1.88	-0.7
Household size out	1.72	4.2	1.82	-3.8
Education out	1.66	0.7	1.88	-0.7
Only GDP	1.81	9.6	1.85	-2.4

If only the economic development is considered in the calculation of the MSW flux generated, then this value is approximately 10% larger in CR scenario and 2% smaller in the MI scenario (Table 7.23). Because in most studies only the GDP is used as an influencing factor on the amount of MSW generated, the indicators of sustainability for the CR and the MI scenarios in these two cases were calculated to determine how results change (Table 7.24).

The most sensitive indicator is the fraction of GDP spent on MSW management, if only the GDP is considered as parameter influencing the specific MSW generation (Table 7.24). This occurs because the total costs are used in the calculation of this indicator, which are directly affected by the total MSW generated. As a rule, the sustainability of each scenario does not change significantly if the MSW flux is derived only as a function of GDP.

Results of the sensitivity analysis carried out for variations of the organic fraction of the MSW in the three scenarios are shown in Table 7.25. In this case, the most sensitive parameter for the CR scenario is the indicator related with the fraction of pretreated waste and the GHG emissions, this is attributed to the fact that both values are highly dependent on the biowaste quantity. In the MI scenario changes, in the waste composition affect primarily the quantity of waste recovered and the greenhouse gas emissions.

Table 7.24 Sensitivity of indicators of sustainability, influence of GDP on waste generation

	CR	Variation [%]	MI	Variation [%]
MSW flux generated	1.81	+10%	1.85	-2%
Recovery	42%	-2.6%	20%	0.9%
Pretreatment	18%	-1.2%	0%	0.0%
GHG	161 kg/(person·day)	3.4%	295 kg/(person·day)	0.4%
Landfill capacity	50%	3.1%	59%	-0.4%
MSW costs/GDP	0.19%	10.9%	0.14%	-2.5%

Table 7.25 Sensitivity of indicators, influence of MSW composition

	CR	CR	MI	MI
Organic amount	**+5%**	**-5%**	**+5%**	**-5%**
Recovery	0.4%	-0.4%	-0.8%	0.8%
Pretreatment	1.1%	-1.1%	0.0%	0.0%
Landfill capacity	0.0%	0.0%	0.1%	-0.1%
GHG	1.0%	-1.0%	0.7%	-0.7%
MSW costs/GDP	0.1%	-0.1%	0.1%	-0.1%

Chapter 8

Summary and Conclusions

Megacities are characterized by a rapid population growth, concentrating considerable quantities of people; they absorb an immense amount of resources and generate vast quantities of solid waste, thus impacting the environment and its use as a sink. Adequate management of municipal solid waste is critical to the health of urban residents, and to the protection of the environment, therefore to the sustainability of cities. An environmental consequence of the process of urbanization in the Metropolitan Region of Santiago, together with its rapid economic development, in recent years, is the large amount of municipal solid waste generated. This fact, together with need of developing a more complete vision of the MSW management, which goes beyond the provision of a service, served as the basis to formulate the goals of the present research.

The first goal of the investigation focused on *identifying the functional systems of the current MSW management* in Santiago de Chile, including the recycling systems and describing *the role of the informal sector*. The field research carried out in Santiago de Chile, together with the material flow analysis elaborated, and systematic literature review allowed identifying and describing the important function that the informal primary collectors have in the MSW management in the Metropolitan Region of Santiago.

The results showed that collection services for MSW are provided nearly in the whole Metropolitan Region of Santiago. MSW management is based on final disposal at landfill sites. 86% of the waste collected is disposed of in sanitary landfills. In the MRS, three relatively new landfills are in operation. These sites comply with international standards, are equipped with bottom liner and a collection system for leachate and in some cases for landfill gas. However, post closure costs are not included in current prices for landfilling. The remainder of the MSW is recycled; the current recycling rates are only achieved by the work carried out by the informal primary collectors. In Santiago de Chile, there is a recycling market for paper, cardboard, glass, aluminum, and scrap, therefore thanks to the work of the informal waste pickers these materials do not end up in landfills but return to the resources cycle. The recycling market provides at the same time a job solution, and a livelihood for the informal collectors involved. The tasks undertaken by this group of people is related to collection, separation, and classification of valuable materials taken out from waste streams. These materials are sold through middlemen to manufacturing companies as secondary raw materials. The informal sector currently contributes with approximately 90% to the total MSW recycling in Santiago de Chile. The current publicly organized recycling system is not able to collect the same amount of recyclable materials than the informal sector. Moreover, there is a lack of laws and binding policies addressed to increase the demand for recycled products within citizens, and to rise environmental sensitivity and awareness of the population.

The second objective of the investigation was *to evaluate the performance of the municipal solid waste management of Santiago de Chile, with respect to sustainability*. To achieve this objective the Integrative Sustainability Concept was used as the theoretical framework. To perform the assessment, indicators of sustainability together with appropriate target values were selected, in close cooperation with Chilean stakeholders. The targets selected took into consideration the existing framework conditions in Chile as well as its priorities in the MSW management area.

The first indicator is the generated flux of MSW; this value has increased by 50% in the last decade and was 1.2 kg/(person·day) in 2007. The second indicator is the quantity of mixed MSW that undergoes pre-treatment before final disposal in landfills, currently there is no biological or thermal treatment previous to landfilling in Santiago de Chile. The third indicator is the quantity of GHG emissions, associated to MSW treatment and disposal; current emissions are in the order of 140 kg $CO_{2\text{-eq}}$/(person·year) for the Metropolitan Region. The forth indicator is the fraction of MSW that is recovered (as material or energy); the recycling fraction is roughly 14%, and there is no energetic recovery from MSW taking place in the MRS. Earnings of primary collectors are approximately 76% of an individual household income. The last indicator corresponds to the share of the GDP spent on MSW management; this share is currently 0.22%.

The comparison between current values and target values showed that the most urgent problems relate to the quantity of mixed waste pretreated, GHG emissions associated with waste treatment and disposal and to the quantity of MSW recovered. These deficits pose a threat for the achievement of sustainable development in the MRS.

Because of *the important role of the informal sector in recycling, its effects on the sustainability of the system were investigated* as part of the third research objective. A total exclusion of the informal sector from the solid waste management system showed negative effects in most indicators of sustainability. Additionally, experiences of organization of informal primary collectors in Latin America were systematically analyzed. Key factors and key stakeholders, which have an influence on their working conditions were identified. Key factors included, among others, the existence of a legal framework for the informal waste sector; the existence of alliances with production companies guaranteeing a reliable industrial market for secondary raw materials, and expansion of activities beyond collection of recyclables, towards further processing and upgrading to add more economic value to materials collected. Key stakeholders included people from the public and private sector, from the civil society and from NGOs. These results should be taken into consideration when designing and planning future waste management strategies for the MRS.

The fourth goal was *to explore different scenarios of MSW management of Santiago de Chile for the year 2030*. Qualitative descriptions as well as quantitative calculations were carried out.

The Business as Usual scenario was characterized by the implementation of current trends and policies. It incorporated a general increase in separate collection of biowaste and recyclable materials, including the participation of organized primary collectors and the expansion of drop-off systems. An increase in climate change prevention policies encouraged the utilization of landfill gas and biogas as an energy source. Technology developments in this scenario encouraged the implementation of mechanical sorting of mixed waste and anaerobic digestion as an option for biological treatment.

The Collective Responsibility scenario was characterized by stronger emphasis on social values against material values and the implementation of more environmental regulations. Recycling and recovery goals were achieved, thanks to waste management strategies which also relied more on the segregated collection of biowaste, drop-off systems and a large commitment to work with the primary waste collectors. In addition, part of the energy content of the waste was recovered by the use of landfill gas, biogas, and by the production of refused derived fuels. Treatment technologies included mechanical sorting of mixed waste, mechanical biological treatment to recover the high calorific fraction of the waste, and anaerobic digestion.

The Market Individualism scenario was characterized by a materialistic culture. The influence of private interests and markets was strong in all political and economic areas. Environmental laws were weak or absent. In this scenario, recovery and recycling of materials from waste flows were introduced only if the economic benefit was large enough. Separate collection was negligible, for both biowaste and recyclable materials. Moreover, there was no interest in working together with the primary collectors or in their organization. Therefore, the sector was still largely informal. Technology advancements and economic profit encouraged the implementation of mechanical sorting applied to mixed waste flows and energy recovery from landfill gas.

The results showed that MSW generation increased in total and in per capita terms in the three scenarios, exceeding the maximum value proposed (1.6 kg/(person·day)). The lowest value was obtained in the CR scenario (1.8 kg/(person·day)) and the largest one in the MI scenario (2.0 kg/(person·day)). The largest recovery rate was obtained in the CR scenario (43%), with a better value than the target proposed (36%); the recovery rate in the BAU scenario was 31%, and the lowest value was obtained in the MI scenario, with a recycling rate of 20%. The main sustainability deficit corresponded, like in the current situation, to mixed waste flow quantities that are not pretreated before disposal in landfills. There was only pre-treatment in the CR scenario, where 18% of the mixed MSW underwent pre-treatment; nevertheless the suggested target value of 50% is not reached. The largest GHG emissions value was obtained in the MI scenario (295 kg $CO_{2\text{-eq}}$/(person·year)). The GHG of the BAU and the CR scenarios were 224 and 155 kg $CO_{2\text{-eq}}$/(person·year) respectively. None of the scenarios reached the suggested target of 71 kg $CO_{2\text{-eq}}$/(person·year). The share of the GDP spent on MSW management showed a negative development, decreasing in the three scenarios, in comparison with current values, being 0.15%; 0.17% and 0.14% in the BAU, CR and MI scenarios respectively. Finally, the income of the primary collectors showed significant improvements only in the CR scenario, with a value of 128% of the individual household income, being 75% and 51% in the BAU and MI scenarios respectively.

In the three scenarios, the large quantities of MSW generated, suggested that there is a need to plan and construct solid waste treatment plants, in order to provide appropriate management to the generated waste quantities. Furthermore, the results obtained showed that the integration of several factors is required in waste management systems, in order to improve sustainability. Technology is only one part of the whole solid waste management structure, and it cannot solve all the associated problems alone, and avoid its associated negative impacts. A sustainable system requires the incorporation of government policy and regulations, sustainable consumption patterns, adequate cost calculations and education, in addition to technological development. Moreover, it is necessary to take advantage of the subsystems already working within the whole system, as it is the case in the informal sector within the waste management of Santiago de Chile.

There is a challenge for the implementation of adequate flexible and cheap treatment technologies, which help to decrease negative environmental impacts. In addition, the costs of these technologies should be affordable, allowing a better financial management.

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Annex A

Information used to define the current situation of the municipal solid waste management in the Metropolitan Region of Santiago de Chile

Table A.5. Recyclable materials collected in María Pinto [Mg/year]

Waste fraction	1999	2002	2007
Paper and cardboard	2	38	115
Glass	1	47	148
Metals	0	2	7
Plastics (PET)	0	20	56
Biowaste	24	126	184
Refused	3	28	85

Source: Huaico, María Pinto 2008

Table A.6. Recyclable materials collected in Ñuñoa [Mg/year]

Waste fraction	2003 –2007	2007 - 2008
Paper and cardboard	2429	762
Glass	1356	444
Metals	377	57
Plastics (PET)	322	92
Plastics (other)	45	45
Nylon	0	45
Tetra Pak	108	33
Refused	2033	557
Total collected	6670	2035

Source: Acuña, Ñuñoa 2008

Table A.7 Materials collected by primary formal collectors

Materials	Amount [kg/(person·day)]
Paper and cardboard	54
Glass	0
Metals	42
Plastic	4
Total	100

Source: Estay 2008, 2009; Alaniz 2009, Pizarro 2005, Casa de la Paz 2007a

Table A.8. Recyclable materials collected in La Florida [Mg/year]

Waste fraction	2003	2004	2005	2007	2008
Paper	97	152	168	194	183
Cardboard	20	29	34	109	118
Glass	111	116	97	160	218
Metals	70	81	94	45	72
Plastics	16	56	17	29	37
Total	314	434	410	537	628

Source: Villegas, La Florida 2008

Table A.9. Recyclable materials deposited at "Punto Limpio", Vitacura [Mg/year]

Punto Limpio	2006	2007	2008
Paper and cardboard	24	182	389
Glass	48	93	220
Metals	16	41	79
Plastics (PET)	6	13	17
Plastics (other)	1	1	0
Tetra Pak	2	1	18
Bulky waste	453	636	
E-waste	11	30	57

Source: Aránsaez 2008, Vitacura

Table A.10. Recyclable materials deposited at domiciliary drop-off containers, Providencia [Mg/year]

Waste fraction	2004	2005	2006	2007
Paper and cardboard	0	0	0	538
Glass	285	366	485	589
Plastics (PET)	10	42	47	59

Source: Varas, 2008, Providencia

Table I.11. Drop-off containers in the Metropolitan Region

Material	Quantity of containers
PET	
Bags (buildings)	1800
Supermarkets	100
Glass	Codeff
Drums (buildings)	3000
Supermarkets	100
	Coanequim
	164
Paper	
Offices	10000
Newspapers	
Churches	31
Supermarkets	64
Schools	65

Source: CONAMA undated

Table A.12. MSW deposited in the landfill Loma los Colorados

Loma los Colorados	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Cerrillos		7,762	0				0	
Cerro Navia	57,206	53,875	53,914	54,500	54,233	56,878	55,322	54,832
Colina	20,213	20,683	21,735	24,058	25,685	29,573	32,084	34,322
Conchali	62,167	61,747	61,552	60,924	60,576	63,882	60,293	62,181
Curacavi	4,720	4,764	4,846	5,009	5,485	5,764	5,635	5,787
Estación Central		18,320	0	0	1,488	9,958	0	0
Huechuraba	32,309	32,071	32,805	35,540	38,657	38,167	39,237	38,932
Independencia	34,943	33,124	32,607	32,384	34,420	34,697	34,452	34,682
Isla De Maipo		3,135	0	0	0	0	0	
La Cisterna	0	34,666	38,574	37,472	37,483	39,066	38,271	39,903
La Reina	44,013	42,142	41,868	41,266	41,541	48,895	48,884	49,438
Lampa	7,018	7,430	8,869	9,540	10,847	12,495	13,992	16,261
Las Condes	108,988	108,761	106,983	107,244	110,716	111,908	113,113	113,757
Lo Barnechea	43,485	42,270	64,138	44,546	48,582	50,070	51,331	66,125
Lo Prado	43,501	39,029	39,179	37,994	37,506	39,290	39,313	39,524
Macul	0	0	0	0	0	0	0	
Maipu		116,794	181,177	189,931	207,604	208,007	200,830	229,979
Ñuñoa	68,389	65,732	65,784	66,535	69,510	70,699	69,902	71,334
P. A. Cerda		14,736	0	0	0	0	0	
Providencia	60,320	59,519	59,324	61,530	64,168	67,009	67,625	69,440
Peñalolen	10,357	29,708	3,461	0	0	0	0	
Pudahuel	68,695	73,683	72,420	74,093	78,842	86,176	84,747	86,463
Puente Alto		555	0	0	0	0	0	
Quilicura	40,872	48,841	50,176	54,422	57,238	60,750	64,839	79,466
Qta. Normal	46,354	47,972	47,712	49,804	49,576	50,864	48,136	50,522
Recoleta	72,909	73,989	72,491	70,906	73,015	72,607	70,441	72,344
Renca	67,153	54,272	55,907	57,516	69,770	60,245	60,281	60,566
San Bernardo		34,503	0	0	0	0	0	
San Joaquin	42,293	44,603	43,384	42,190	44,908	46,076	45,077	45,395
San Miguel	16,108	37,525	37,168	38,217	40,620	40,627	39,008	38,295
Santiago	137,540	130,153	130,568	133,693	134,724	143,145	145,135	147,022
Talagante		14,432	16,410	16,937	8,821	0	0	
Vitacura	45,407	42,805	41,920	44,228	46,769	48,982	48,251	49,344
Tiltil (3)			0	0	0	0	0	
TOTAL	**1,134,960**	**1,399,601**	**1,384,972**	**1,390,479**	**1,452,784**	**1,495,830**	**1,476,199**	**1,555,914**

Table A.13. **MSW deposited in the landfill Lepanto**

Lepanto	**2001**	**2002**
Buin	17,504	3,783
C. De Tango	4,546	1,098
Cerrillos	29,019	9,249
El Bosque	65,069	24,245
Est. Central	48,069	15,620
Isla De Maipo	6,251	1,358
La Cisterna	0	0
La Florida	135,182	44,845
La Granja	52,773	18,422
La Pintana	57,724	19,106
Lo Espejo	42,713	15,039
Macul	45,430	16,533
Maipu	158,734	49,458
P.A. Cerda	45,801	16,225
Paine	3,138	709
Peñalolen	73,569	25,277
Peñaflor	18,172	4,425
P. Hurtado	10,781	2,293
Pirque	4,024	1,038
Pte. Alto	141,071	47,781
San Bernardo	76,795	23,671
San Miguel	20,877	0
San Ramon	34,817	11,391
San Joaquin	0	0
San Jose De Maipo	0	0
Santiago	0	0
Total	1,092,059	351,566

Table A.14. MSW deposited in the landfill Santa Marta

Santa Marta	2002	2003	2004	2005	2006	2007	2008
Buin	6,000	22,235	18,980	19,264	21,408	21,887	21,497
Calera De Tango	1,458	5,050	6,244	6,739	7,236	3,916	0
Cerrillos	3,821	0	0	0	0	0	
El Bosque	36,080	35,441	61,332	62,602	65,231	63,665	70,771
El Monte	0	0	0	0	4,594	8,272	5,780
Est. Central	5,935	0	0	0	0	0	
Isla De Maipo	1,462	0	0	0	0	0	
. La Granja	26,037	28,052	52,650	52,398	52,763	52,710	54,366
La Florida	81,448	126,669	131,919	130,463	136,212	145,913	158,486
La Pintana	35,780	54,024	56,868	56,210	59,905	57,708	58,207
Lo Espejo	21,698	43,309	42,068	41,781	43,580	41,697	43,249
Macul	29,044	43,617	42,222	42,607	42,469	44,387	48,706
Pac	5,947	0	0	0	0	42,564	45,608
Paine	1,490	3,763	0	7,130	13,205	13,776	14,842
Padre Hurtado	2,632	9	0	0	0	0	
Penaflor	5,823	4,991	0	0	0	0	
Peñalolen	10,160	0	0	0	0	0	8,301
Pirque	1,459	3,813	3,808	4,352	4,915	5,711	5,729
Puente Alto	85,119	139,369	150,714	159,395	173,825	174,238	180,607
San Bernardo	5,685	0	0	0	0	0	
San Jose De Maipo		4,450	5,270	5,138	4,793	6,298	5,260
San Ramon	22,572	33,350	33,948	33,523	33,909	33,061	32,056
Talagante	0		0	8,358	17,655	18,321	17,397
Particulars	0	2,209		95,749	171,726	163,752	
Total	389,650	548,142	606,023	629,960	681,700	734,124	770,862

Table A.15. MSW deposited in the landfill Santiago Poniente

Santiago Poniente	2002	2003	2004	2005	2006	2007	2008
Cerro Navia							1
Cerrillos	5,990	27,565	29,387	30,935	31,316	32,786	36,437
El Bosque	7,924	23,123	0	0	0	0	
El MONTE							2,432
Est. Central	8,254	50,171	51,113	50,653	48,915	53,497	57,930
La Granja	6,046	19,327	0	0	0	0	
La Florida	5,034	1,605	0	0	0	0	
Lo Espejo	5,150	1,456	0	0	0	0	
Padre Hurtado	1,724	11,702	12,654	13,473	14,162	14,921	15,124
Puente Alto	6,363	2,428	0	0	0	0	
Pedro A. Cerda	7,032	42,398	42,642	40,577	27,294	0	0
Peñalolen	16,882	76,108	77,681	80,183	82,910	85,144	82,934
San Bernardo	12,633	74,111	76,484	84,976	92,816	92,753	95,971
Isla De Maipo	0	6,475	7,134	7,645	5,141	8,086	9,056
Peñaflor	0	14,545	20,504	21,669	22,307	22,466	23,435
Paine	0	5,463	12,254	5,584	0		0
Calera De Tango	0	12	0	0	0	3,579	8,091
Tot.Particulares	203	0	0	0	0	0	
Total	83,032	356,489	329,853	335,695	324,861	313,232	331,411

Source Table A.12 to Table A.15: SEREMI RM 2008.

Table A.16. MSW recycled in the Metropolitan Region of Santiago

Year	Paper/cardboard	Glass	Metals	Plastic	Tetra Pak
1995	2,000	891	0		
1996	2,500	2,520	0		
1997	3,200	3,600	11,666		
1998	53,127	5,400	13,460		
1999	61,673	7,851	17,412		
2000	83,589	10,261	30,562	1,950	
2001	132,579	11,869	32,273	1,620	200
2002	128,291	13,583	37,038	1,733	378
2003	131,453	13,341	43,181	12,890	392
2004	124,157	13,870	53,239	14,540	402
2005	183,285	13,300	102,900	14,500	386
2006	224,864	14,746	134,066	15,000	410
2007	229,772	15,500	145,854	15,000	419

Source: CONAMA 2009

Table A.17 Default characteristics of residual waste

	Dry matter (DM) [%]	Organic dry matter (ODM) [%DM]	Carbon [%ODM]	Total organic carbon [%C]	Biogenic $\text{Carbon}_{\text{fraction}}$ [%]
Organic food	45	100	51	100	51
Yard waste	43	100	50	100	50
Cardboard	70	95	49	99	46
Paper	67	95	49	99	46
Plastics	85	75	83	5	3
Tetra Pak	75	75	59	60	27
Hygienic articles	50	75	57	90	38
Glass	95	0	47	0	0
Metals	90	0	48	0	0
Leather	70	60	51	65	20
Wood	70	50	49	100	25
Textiles	70	60	51	65	20
Dust/Ash	90	0	48	0	0
Other	80	40	49	100	20

Source: Fricke et al. 2002

Table A.18. Composition of MSW deposited in Loma Los Colorados Landfill Winter 2008 [%]

Municipality	Organics	Yard Waste	Paper	Cardboard	Plastics	Tetrapack	Hygienic articles	Rubber	Leather	Glass	Metals	Wood	Textiles	Dust /Ash	Batteries	Bones	Fruit Pit	Ceramics	Other	Special Waste
Cerro Navia	64.0	0.1	11.8	1.8	5.3	0.3	2.3	0.1	0.3	5.4	0.7	0.6	4.9	0.8	0.3	0.2	0.1	0.3	0.0	0.8
Conchali	55.2	4.7	12.5	2.3	10.4	0.6	6.5	0.3	0.1	1.9	0.8	0.0	2.2	0.9	0.0	0.7	0.1	0.5	0.0	0.5
Huechuraba	48.9	0.1	12.9	2.8	11.0	1.1	11.3	0.0	0.0	2.8	1.6	0.0	2.7	3.0	0.0	0.4	0.6	0.5	0.1	0.4
Independencia	46.7	2.1	19.2	2.5	9.6	0.6	8.9	0.3	0.6	3.4	1.1	0.4	1.4	0.4	0.1	1.5	0.6	0.0	0.0	0.6
La Cisterna	48.1	3.5	14.1	2.8	12.6	0.7	4.5	0.0	0.0	3.4	0.6	0.1	3.9	3.6	0.0	1.4	0.4	0.3	0.0	0.1
La Reina	46.3	1.3	20.2	2.3	11.8	1.4	4.3	0.1	0.0	3.6	1.1	0.1	4.3	1.2	0.0	0.2	1.1	0.4	0.0	0.4
Las Condes	57.9	2.5	11.7	3.7	9.0	1.1	3.0	0.2	0.0	5.1	1.4	1.9	0.8	0.2	0.0	0.7	0.8	0.0	0.0	0.2
Lo Barnechea	38.9	5.4	22.6	2.2	9.4	1.3	1.5	0.0	0.0	6.1	0.6	0.0	0.7	9.9	0.1	0.1	0.2	0.2	0.0	0.9
Lo Prado	55.9	0.2	13.6	2.4	10.1	0.9	7.1	0.9	0.0	3.0	0.8	0.1	2.0	0.7	0.0	1.8	0.5	0.0	0.0	0.1
Maipu	50.5	1.9	10.6	4.9	11.9	0.4	6.4	0.1	0.2	2.4	1.2	0.4	6.9	0.9	0.0	0.5	0.1	0.5	0.0	0.1
Ñuñoa	56.3	3.8	12.4	2.4	9.1	1.0	4.6	0.1	0.0	2.0	1.1	0.4	4.3	0.0	0.1	0.8	0.4	0.0	0.8	0.5
Providencia	45.8	0.7	19.5	5.6	13.9	1.5	2.2	0.0	0.0	2.9	1.3	4.0	0.6	0.1	0.0	1.0	0.5	0.0	0.0	0.4
Pudahuel	56.0	1.3	13.1	2.4	8.7	0.8	5.3	0.0	0.0	3.5	0.9	0.3	5.8	0.3	0.1	0.1	0.3	0.6	0.0	0.4
Quilicura	41.6	8.6	8.6	3.9	8.3	0.8	14.4	0.0	0.0	6.9	1.2	0.4	2.9	0.5	0.0	0.4	0.2	1.1	0.0	0.3
Quinta Normal	38.5	8.5	12.5	3.0	11.1	0.8	15.3	0.0	0.5	4.0	0.9	0.1	1.3	1.5	0.0	1.0	0.3	0.2	0.0	0.4
Recoleta	46.2	1.6	13.4	2.3	10.4	0.8	15.5	0.1	0.3	2.5	1.0	0.1	4.2	0.0	0.1	1.0	0.3	0.1	0.0	0.2
Renca	47.5	0.2	15.4	9.7	11.8	0.8	2.1	0.3	2.4	0.5	2.2	0.1	4.0	1.2	0.1	0.8	0.2	0.2	0.0	0.5
San Joaquin	51.5	1.1	15.7	2.5	9.2	0.6	7.1	0.2	0.3	2.1	0.5	0.3	3.9	3.4	0.0	0.8	0.2	0.1	0.0	0.6
San Miguel	50.1	2.0	12.7	3.2	12.4	1.0	4.8	0.3	0.0	4.1	0.7	0.0	3.3	2.8	0.0	1.3	0.1	0.7	0.2	0.4
Santiago	51.1	1.3	9.7	2.5	13.3	1.2	7.1	0.1	0.0	7.2	0.6	0.4	4.7	0.1	0.0	0.3	0.3	0.0	0.0	0.3
Vitacura	45.2	13.1	13.4	2.9	9.6	0.7	0.3	0.0	0.0	6.0	2.5	0.3	1.5	0.2	0.1	0.8	0.6	3.1	0.0	0.1
Curacavi	45.7	0.9	13.9	2.4	8.7	0.8	16.7	0.5	0.2	2.0	1.6	0.1	3.6	1.9	0.3	0.3	0.4	0.0	0.0	0.3
Colina	45.6	0.0	13.6	3.1	12.2	1.7	7.9	0.5	0.0	4.1	1.8	1.0	1.5	5.3	0.0	0.7	0.4	0.4	0.0	0.2
Lampa	41.8	0.0	13.8	3.3	10.2	0.9	16.3	0.8	0.0	2.8	1.3	0.0	5.9	0.0	0.0	0.3	0.2	0.5	0.0	1.8
Total	50.3	2.6	13.0	3.6	10.5	0.8	6.6	0.1	0.2	3.6	1.1	0.6	3.9	1.2	0.0	0.6	0.3	0.4	0.1	0.3

Table A.19. Composition of MSW deposited in Loma Los Colorados Landfill Spring 2009 [%]

Municipality	Organics	Yard Waste	Paper	Cardboard	Plastics	Tetrapack	Hygienic articles	Rubber	Leather	Glass	Metals	Wood	Textiles	Dust /Ash	Batteries	Bones	Fruit Pit	Ceramics	Other	Special Waste
Cerro Navia	66	0	7	2	9	1	4	1	0	1	0	1	4	2	0	0	0	0	0	1
Conchalí	61	1	7	2	10	1	7	1	0	4	2	0	1	2	0	1	1	0	0	0
Huechuraba	51	1	16	4	9	2	5	1	0	1	2	0	4	2	1	0	0	0	0	1
Independencia	49	0	19	4	9	1	11	0	0	2	1	1	3	0	0	0	0	0	0	0
La Cisterna	56	0	8	5	10	1	10	0	0	5	2	0	2	0	0	0	0	0	0	0
La Reina	57	0	6	3	12	1	7	0	0	4	1	2	3	1	1	0	1	1	0	0
Las Condes	53	0	14	5	10	1	5	0	0	5	1	0	2	0	1	0	0	0	0	1
Lo Bernechea	54	1	11	6	11	1	4	1	0	3	1	0	6	0	0	0	1	0	0	0
Lo Prado	59	0	10	2	14	2	4	0	0	2	1	0	3	0	0	1	0	1	0	0
Maipu	52	3	12	3	9	0	4	1	1	4	1	1	2	3	0	1	0	1	1	1
Ñuñoa	52	0	15	4	13	0	8	0	0	1	1	0	2	0	0	0	0	1	0	1
Providencia	47	1	23	5	9	1	6	1	1	2	1	0	1	0	0	0	0	0	1	1
Pudahuel	64	0	11	2	8	1	6	1	0	1	1	1	2	1	0	1	0	0	1	1
Quilicura	55	2	11	4	11	1	6	2	0	2	1	0	2	1	0	1	0	1	0	1
Quinta Normal	66	0	9	4	9	0	4	0	0	4	0	0	2	0	0	0	0	0	0	0
Recoleta	62	0	11	2	13	1	2	0	0	2	1	1	3	1	0	0	0	0	0	1
Renca	61	3	10	2	9	0	5	1	0	3	1	0	3	0	0	0	0	0	0	1
San Joaquin	53	0	13	4	11	1	6	0	0	3	1	0	5	1	0	1	0	0	0	0
San Miguel	55	1	11	3	12	1	8	0	0	2	1	0	4	1	0	0	1	0	0	0
Santiago	50	0	14	2	13	2	6	0	0	3	2	0	3	3	0	1	0	0	0	0
Vitacura	54	1	13	4	13	1	2	0	0	7	2	0	0	0	0	0	0	0	0	1
Curacavi	53	0	11	4	9	0	10	0	0	2	1	0	5	1	0	0	2	0	0	0
Colina	49	0	12	4	12	1	10	1	0	4	1	1	4	0	0	0	0	1	0	0
Lampa	61	0	7	2	8	0	14	2	0	1	1	1	3	0	0	0	0	1	0	0
Til Til	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	55.6	1.1	12.0	3.1	10.4	0.8	5.4	0.6	0.3	3.1	1.1	0.5	2.4	1.3	0.1	0.5	0.3	0.4	0.3	0.8

Source Oddou 2008

Table A.20 Calculated characteristics of MSW in Santiago de Chile

	Composition MSW[1] [%]	**TOC_{MSW} [g/kg]**	**Water $content_{MSW}$ [%]**
Organic food	53.6	273.3	29.5
Yard waste	1.8	8.8	1.0
Cardboard	3.2	14.8	0.5
Paper	12.2	56.1	4.0
Plastics	10.2	3.2	1.5
Tetra Pak	0.8	2.1	0.2
Hygienic articles	6.5	25.2	3.3
Glass	3.2	0	
Metals	1.1	0	
Leather	0.2	0.4	0.1
Wood	0.5	1.1	0.1
Textiles	3.2	6.3	1.0
Dust/Ash	1.2	0.0	
TOTAL		**391.7**	**41.3**

Source based on Oddou 2008

The calculated biodegradable organic fraction is 391.7 kgC_{org}/Mg_{waste} with a water content of 41.3%, therefore the degradable organic carbon content is 230.1 kg $C_{org}/Mg_{MSW(HM)}$. This value seems plausible for the current situation in MRS, where the amount of segregated collection of biogenic waste is negligible, thus it is expected that the organic carbon content should be higher than that of European countries. In a study carried out by the Austrian Environmental Federal Office (Rolland 2003), on the biodegradable carbon content of residual waste in Austria, it was observed a reduction from 230 kg_{carbon} per ton of humid MSW in 1960 to 120 kg_{carbon} per ton of MSW in 2003. This reduction was attributed to the strong implementation of separate collection of biowaste and paper. Moreover, in the same study data collected by Tabasaran & Rettenberger are presented, indicating a rage from 170 to 220 $kg_{carbon}/Mg_{MSW\ (HM)}$, for the total organic carbon of the residual waste of Germany in the year 1987. Today, the estimates for residual waste in Germany are lower, which is attributed to separate collection of biowaste. Besides, the influence of segregated collection in the organic carbon content, the higher value for Santiago de Chile can be explained for the different consumption patters between these countries, in particular cooking habits and consumption of fresh fruits and vegetables.

Table A.21 **Prices of secondary raw materials**

Material	Price [US$/Mg]
White paper	160
Cardboard	74
Newspaper	66
Magazines	76
PET bottles	76
Glass (average)	50
Ferrous metals	100
Aluminum	900
Copper	4000
Iron	120

Source: Recupac, Sorepa, Yuen 2009

Table A.22. Net calorific value of MSW arriving at Loma los Colorados

Composition	Humid Base	Net Calorific Value[a] [kJ/kgHM]	Calculated Net Calorific Value[a] [kJ/kgHM]
Organics	52.95%	7,300	3,759
Yard waste	1.86%	5,300	99
Paper	12.45%	6,600	822
Cardboard	3.36%	8,800	296
Plastics	10.46%	25,00	2,278
Tetrapack	0.80%	16,800	134
Diapers/sanitary towels	6.01%	7,100	427
Rubber	0.38%	11,800	45
Leather	0.24%	12,300	30
Glass	3.36%	-	
Metals	1.13%	-	
Wood	0.52%	9,500	49
Textiles	3.17%	12,300	390
Dust /Ash	1.25%	4,600	58
Batteries	0.07%	-	
Bones	0.54%	11,800	64
Fruit pit	0.30%	11,800	35
Ceramics	0.41%	-	
Other	0.19%	11,800	22
Special waste	0.55%		
Total	**100%**		**8,497**

a: Loll 2002

Table A.19 MSW management costs recovery degree in Santiago de Chile -2007
(Source: SINIM, SII 2009)

Municipality	Land tax [$10^3\,\mathrm{US\$}$]	Direct fee (including municipal patent) [$10^3\,\mathrm{US\$}$]	Costs [$10^3\,\mathrm{US\$}$]	Recovery costs [%]
Santiago	1982	4138	4612	133%
Cerrillos	78	192	1410	19%
Cerro Navia	0	207	1708	12%
Conchalí	73	398	2370	20%
El Bosque	101	437	2707	20%
Estación Central	185	556	1747	42%
Huechuraba	449	417	1756	49%
Independencia	183	426	2143	28%
La Cisterna	318	639	1325	72%
La Florida	1331	2462	6219	61%
La Granja	36	316	1553	23%
La Pintana	20	293	1898	17%
La Reina	1284	196	2186	68%
Las Condes	7945	0	5496	145%
Lo Barnechea	1674	121	3229	56%
Lo Espejo	0	196	1235	16%
Lo Prado	27	239	1276	21%
Macul	460	500	1764	54%
Maipú	781	2639	5985	57%
Ñuñoa	2450	0	3559	69%
Pedro Aguirre Cerda	90	0	1609	6%
Peñalolén	624	525	3404	34%
Providencia	3860	1322	4112	126%
Pudahuel	0	589	2741	21%
Quilicura	87	222	2261	14%
Quinta Normal	135	355	1578	31%
Recoleta	213	1251	2455	60%
Renca	35	194	2202	10%
San Joaquín	221	373	1893	31%
San Miguel	647	308	1508	63%
San Ramón	28	158	1002	19%
Vitacura	3635	442	5397	76%
Puente alto	202	471	5503	12%
Pirque	135	0	249	54%
San José de Maipo	79	7	296	29%
Colina	267	188	2171	21%
Lampa	29	38	344	20%
Til Til	26	7	0	
San Bernardo	146	551	4218	17%
Buin	101	158	826	31%
Calera de Tango	187	0	219	86%
Paine	65	71	510	27%
Melipilla	76	79	732	21%
Alhué	0	0	22	0%
Curacaví	9	39	112	43%
María Pinto	0	7	96	7%

Table A.19 Cont. MSW management costs recovery degree in Santiago de Chile -2007

(SINIM, SII 2009)

Municipality	Land tax [10^3US$]	Direct fee (including municipal patent) [10^3US$]	Costs [10^3US$]	Recovery costs [%]
San Pedro	0	0	46	0%
Talagante	36	152	761	25%
El Monte	24	67	63	144%
Isla de Maipo	22	23	504	9%
Padre Hurtado	13	57	490	14%
Peñaflor	54	99	794	19%
Total	30426	22123	102295	
Recovery costs [%]	30	22		**51**

Annex B

Information related to Risk Habitat Megacity Framework Scenarios

Table B.1 Driving factor categories – driving factors – keywords – framework scenarios

Category:	**Economic development**
Driving factor	**Keyword**
Integration into world markets	Degree of liberalization Trade agreements Degree of foreign trade dependency
Structure of the Economy	Share of services and finance Share of manufacturing Share of construction branch Share of mineral, beer and wine branch Share of informal economy
Productivity development (role of technology)	Labor Resources
Emergence of new big players in global markets, (e.g. BRICS countries)	Proportional share of BRICS in trade Managing relative advantages (comparative and competitive)/motivations of exchange
Category:	**Institutional framework / governance**
Level of international co-operation	Level of multilateral collaboration (global) Regional dimension of roles (LA, Asia-Pacific)
National level: focus on market or state regulation	Market role State role
Local government role	Municipal role Regional role Degree of co-operation between municipalities Regional democratic representation
Civil society role	Level of Civil society influence Diversity of issues for mobilization / action Role of political parties Role of social partnerships (incl. union activity; employers-employees)
Private sector role	Influence in the economy Influence in policy-making
Informal dynamics	Importance of informal decision making / actions
Category:	**Demographics**
Regional population development	Total population change (RMS – 52 comunas) Birth / death ratio
Change of urban population	Total population change (RMS) Urban population change (AMS - 34 comunas) Rural population change (rest of 18 non-metrop. comunas) Change in birth rate Change in death rate Net migration balance (relation between inward and outward migration; "+" means rise in region)
Category:	**Technological Development**
Role of technologies	Importance in relation to other (societal, institutional, etc.) problem solution approaches Firm based promotion Social acceptance
Guiding visions	Emphasis on high-tech in relation to intermediate-tech
R & D policies (private and public)	Degree of strategic perspective Investments

Table B.1 Continuation Driving factor categories – driving factors – keywords – framework scenarios

Category:	**Societal value system**
Consumption patterns	Importance of material relative to non-material (social, cultural, spiritual, …) consumption Equality of distribution of consumption among socio-economic groups
Life styles	Degree of acceptance / tolerance of diverse life styles Role of media in life style choices Importance of Christian beliefs
Access e. g. to jobs, technologies	Existing access structure (according to social / spatial groups)
Category:	**Environmental and climate change**
Global warming / climate change	Water availability Temperature Biodiversity change Disease cases
Rising stratospheric ozone concentration	Diseases (cancer, ...) Negative impacts on plants
Category:	**Education**
Access	Equitable distribution between societal groups Proximity between supply and demand
Quality	Quality of public supply compared to private Teacher education quality Investment in infrastructure (buildings and materials) Results (abilities of scholars) Life-long learning
Expenditure	Share of educational expenditure in total household spending Public share of spending
Category:	**Resources**
Non-renewable resource limitations and availability	Effectiveness of resource policy to reduce depletion rates

Developed by: J. Barton, J. Kopfmüller, V. Stelzer, within the RHM Project

Table B.2 Driving factors key words: tendencies for the scenarios in 2030

BAU assumptions global level	Business as Usual	Collective Responsibility	Market Individualism
Economic development			
Integration into the world market degree of protectionism / openness of international markets			
Continuation of previous liberalization, deregulation and privatization processes; moderate reduction of protectionism	Degree of liberalization		
	+	0	++
	Trade agreements		
	+	0	++
	Degree of foreign trade dependency		
	+	-	++
Structure of the economy			
Continuation of diversification of branches; Increase of number and importance of global enterprises	Share of services and finance		
	+	+	++
	Share of manufacturing		
	-	+	--
	Share of construction branch		
	+	++	+
	Share of mineral, beer and wine branch (exports from MRS)		
	Share of informal economy		
	0	-	+
Productivity development			
Increase of labor productivity higher than resource productivity	Labor productivity		
	+	-	++
	Resource productivity		
	+	++	+
Institutional framework/governance			
Level of international cooperation			
Increased international co-operation, but mainly in trade relationships; Strong position of international economic organizations; Weakening of multilateralism and multi-level governance in other fields	Level of multilateral collaboration (global)		
	+	++	0
	Regional dimension of roles		
	+	++	0
National level: focus on market or state regulations			
Focus on market instead of state regulation	Market role		
	0	-	+
	State role		
	0	++	--
Local government role			
More competition between local governments; Increasing role of networks of local actors	Municipal role		
	0	+	-
	Regional role		
	0	++	-
	Degree of collaboration between municipalities		
	0	+	-
	Regional democratic representation		
	0	++	-

Table B.2 Continuation

	BAU	CR	MI
Civil society role			
Growing influence of NGOs Increasing institutionalized participation processes	Level of civil society influence		
	+	++	+
	Diversity of issues for mobilization/action		
	+	++	0
	Role of political parties		
	-	--	--
Slowly increasing role of civil society; Reduced influence of trade unions	Social partnerships (including union activity; employers/ees)		
	0	++	-
Private sector role			
Growing influence of private actors on local level	Influence in the economy		
	+	-	++
	Influence in policy-making		
	0	-	+
Informal dynamics			
Informal dynamics (informal settlements, informal economy, corruption)	Importance of informal decision-making/actions		
	0	-	+
Demographics			
Regional population development			
	Total population change		
	+	+	+
	Birth/death ratio		
	+	+	O
Change of urban population			
	Total population change		
	+	+	+
	Urban population change		
	+	+	+
	Rural population change		
	-	0	-
	Change in birth rate		
	-	0	-
	Change in death rate		
	-	-	0
	Net migration balance		
	-	-	0
Technological development			
Role of technologies			
	Importance in relation to other (societal, institutional) problem solution approaches		
	+	0	++
	Firm based promotion		
	+	+	++
	Social acceptance		
	+	+	++
Guiding visions of technological promotion			
	Emphasis on hi tech over intermediate tech		
	++	-	++
	Research and development policies		
	Degree of strategic perspective		
	+	++	0
	Investments		
	+	+	++

Table B.2 Continuation

	BAU	CR	MI
Societal value system			
Consumption patterns	Importance of material relative to non-material consumption		
	+	-	++
	Equality of distribution of consumption among socio-economic groups		
	0	++	-
Lifestyles	Degree of acceptance/tolerance of diverse lifestyles		
	+	++	+
	Role of media in lifestyle choices		
	++	+	++
	Importance of Christian beliefs		
	0	0	-
Access, e.g. Jobs, technologies			
	Existing access structure (according to social/spatial groups)		
	0	+	-
Environmental and climate change			
Global warming/climate change			
	Water availability		
	-	-	-
	Temperature		
	+	+	+
	Biodiversity change		
	+	+	+
	Disease cases		
	+	0	+
Rising stratospheric ozone concentration			
	Diseases		
	+	+	+
	Negative impacts on plants		
	+	+	+
Education			
Access			
	Equitable distribution between societal groups		
	0	+	-
	Proximity between supply and demand		
	+	+	0
Quality			
	Quality of public supply compared with private supply		
	-	+	-
	Teacher education quality		
	0	++	+
	Investment in infrastructure (buildings and materials)		
	+	++	+
	Results (abilities of scholars)		
	+	++	+
	Lifelong learning		
	0	++	0
Expenditure			
	Share of educational expenditure in total spending per household		
	+	- Will be financed by other means (taxation, etc.)	+
Public share of educational spending			
	-	++	--
Resources			
Non-renewable resource limitations and availability			
	Efficacy of resource policy to reduce depletion rates		
	-	+	--

Annotation:

++ : strong increase
+ : increase
0 : rather constant in time
- : decrease
-- : strong decrease

Source: Developed by: J. Barton, J. Kopfmüller, V. Stelzer, D. Heinrichs, K. Krellenberg within the Risk Habitat Megacity Project

Table B.3 Quantitative variables: tendencies and scenario estimations[xvi]

Variables	History	BAU	CR	MI
Total population (52 municipalities) [millions]	1990: 5.19 1995: 5.70 2000: 6.17 2005: 6.54	2010: 6.88 2015: 7.19 2020: 7.46 2025: 7.73 2030: 8.00	2010: 6.88 2015: 7.15 2020: 7.45 2025: 7.55 2030: 7.60	2010: 6.88 2015: 7.27 2020: 7.58 2025: 7.86 2030: 8.23
GDP yearly growth rate Chile [%] nominal[xvii]	1982-1992: 27 1992-2002: 12 2002-2008: 11	2010: 5 2015: 10 2020: 9 2025: 8 2030: 7	2010: 5 2015: 9 2020: 8 2025: 7 2030: 6	2010: 5 2015: 11 2020: 10 2025: 9 2030: 8
Inflation rate Chile [%]	1993: +12.7 1995: +8.2 1997: +6.1 1999: +3.3 2001: +3.6 2003: +2.8 2005: +3.1 2007: +4.4 2008: +8.7 2009: +1.5	2010: 2 2015: 5 2020: 4 2025: 4 2030: 3	2010: 2 2015: 4 2020: 3 2025: 3 2030: 2	2010: 2 2015: 6 2020: 5 2025: 4 2030: 4
GDP yearly growth rate Chile [%] real The real rate is the calculation of the nominal rate minus inflation		2010: 3 2015: 5 2020: 5 2025: 4 2030: 4	2010: 3 2015: 5 2020: 5 2025: 4 2030: 4	2010: 3 2015: 5 2020: 5 2025: 5 2030: 4
GDP percentage RMS Contribution to national GDP [%]	1985-1992: 39 1993-2002: 41 2003-2006: 43	2010: 43 2015: 44 2020: 44 2025: 45 2030: 45	2010: 43 2015: 42 2020: 41 2025: 40 2030: 40	2010: 43 2015: 44 2020: 45 2025: 46 2030: 47
GDP yearly growth rate RMS [%]real		2010: 3,0 2015: 5,1 2020: 5,1 2025: 4,2 2030: 4,2	2010: 3,0 2015: 4,9 2020: 4,8 2025: 3,7 2030: 3,7	2010: 3,0 2015: 5,1 2020: 5,2 2025: 5,3 2030: 4,4
Household income MRS: [Chilean pesos per month in prices from 2000]	1992: 555,187 1994: 602,900 1996: 684,600 1998: 687,254 2000: 625,022 2003: 700,305 2006: 713,691	2010: 740,000 2015: 780,000 2020: 800,000 2025: 820,000 2030: 840,000	2010: 740,000 2015: 770,000 2020: 790,000 2025: 810,000 2030: 820,000	2010: 740,000 2015: 760,000 2020: 780,000 2025: 800,000 2030: 810,000

[xvi] All scenario projections are based on qualitative considerations based on consistency with global processes, regional tendencies and storyline provisions (except the population projections based on INE calculations to 2020)

[xvii] [xvii] Where a number for projections is presented for a five year step in this and following rows, this number denotes the value for each of the five years in this step. It should not be interpreted as a total for the five year period.

Table B.3 Quantitative variables: tendencies and scenario estimations

Variables	History	BAU	CR	MI
Share of economic branches (percentage of regional GDP)	2003 2006 M 17.3 17.1 C 14.3 15.6 T 11.3 12.2 F 26.9 28.0 M=manufacturing C=commerce, restaurants, hotels T=transport/comunications F=financial, business services	2010 M 17.1 C 16.0 T 13.0 F 28.2 2015 M 17.1 C 17.0 T 14.0 F 28.6 2020 M 17.0 C 18.0 T 15.0 F 29.0 2025 M 17.0 C 19.0 T 16.0 F 29.5 2030 M 17.0 C 20.0 T 17.0 F 32.0	2010 M 17.1 C 16.0 T 13.0 F 28.2 2015 M 17.5 C 17.5 T 14.5 F 27.0 2020 M 18.0 C 18.5 T 16.0 F 26.0 2025 M 19.0 C 19.0 T 17.0 F 25.0 2030 M 20.0 C 19.5 T 18..0 F 23.0	2010 M 17.1 C 16.0 T 13.0 F 28.2 2015 M 16.0 C 17.0 T 14.0 F 30.0 2020 M 14.0 C 18.0 T 15.0 F 31.0 2025 M 12.0 C 19.0 T 16.0 F 32.0 2030 M 10.0 C 20.0 T 17.0 F 34.0
Persons per household MRS	1992: 3.8 2002: 3.7 2006: 3.7	2010: 3.6 2015: 3.4 2020: 3.3 2025: 3.1 2030: 3.0	2010: 3.6 2015: 3.5 2020: 3.4 2025: 3.3 2030: 3.2	2010: 3.6 2015: 3.4 2020: 3.2 2025: 3.0 2030: 2.8
Years of schooling, RMS (average years of primary, secondary and tertiary education; respondents 15+ years of age)	1990: 9.9 1992: 9.8 1994: 9.9 1996: 10.3 1998: 10.5 2002: 10.7 2003: 11.0 2006: 10.8	2010: 11.0 2015: 11.2 2020: 11.4 2025: 11.6 2030: 11.8	2010: 11.0 2015: 11.3 2020: 11.6 2025: 11.9 2030: 12.2	2010: 11.0 2015: 11.1 2020: 11.2 2025: 11.3 2030: 11.4
Total number of private vehicles registered in the city	2001: 740,420 2002: 741,718 2003: 750,455 2004: 808,183 2005: 859,018 2006: 918,319 2007: 971,895 2008: 1,026,697	2010: 1,100,000 2015: 1,400,000 2020: 1,800,000 2025: 2,100,000 2030: 2,600,000	2010: 1,100,000 2015: 1,300,000 2020: 1,500,000 2025: 1,800,000 2030: 2,000,000	2010: 1,100,000 2015: 1,500,000 2020: 2,000,000 2025: 2,300,000 2030: 2,800,000
Share of exports (in %, by value) of copper (refined, unrefined, concentrates) of total exp. for Chile	1998 35.9 2000 43.8 2004 47.3 2006 58.0 2008 51.8 2009 53.5	2010: 55.0 2015: 52.0 2020: 52.0 2025: 50.0 2030: 49.0	2010: 55.0 2015: 47.0 2020: 45.0 2025: 43.0 2030: 40.0	2010: 55.0 2015: 55.0 2020: 56.0 2025: 56.0 2030: 57.0

Source: Developed by: J. Barton, J. Kopfmüller. V. Stelzer within the RHM Project

Annex C

Data used to estimate MSW generation in BAU scenario

Table C.1 shows the GDP of MRS and the waste landfilled in from 1995 to 2008. Waste landfilled corresponds to the specific amount of waste arriving at landfills in MRS. Because this quantity includes not only the municipal solid waste, but also the yard waste and waste from street cleaning, which are assumed not to be dependant on GDP (350,000 Mg in 2006), the data has been corrected according to Wens (2008).

Table C.1 Data to calculate quantitative functions in the BAU scenario

Year	GDP [PPP International US$ 2009/(person·year)][a]	Specific waste landfills [kg/(person·day)][b]	Waste landfilled (without considering public cleaning) [kg/(person·day)]	Waste recycled [kg/(person·day)]	Recycling rate (without considering public cleaning) [%]
1995	7,752	0.86	0.67	0.00	0.21
1996	8,346	0.89	0.71	0.00	0.33
1997	8,928	0.86	0.74	0.01	1.14
1998	9,178	0.89	0.82	0.03	3.84
1999	9,136	0.91	0.86	0.04	4.34
2000	9,602	0.99	0.91	0.06	5.80
2001	10,046	1.02	0.87	0.08	8.29
2002	11,260	1.07	0.87	0.08	8.62
2003	11,350	1.02	0.85	0.09	9.22
2004	12,183	1.03	0.86	0.09	9.27
2005	13,061	1.00	0.88	0.13	12.97
2006	13,957	1.01	0.91	0.16	15.09
2007	14,874	1.03	0.90	0.17	15.58
2008	15,523	1.06	0.95		

a: IMF undated b: Seremi Salud

Table C.2 Projected waste generated in the BAU scenario

Year	GDP [US$2009/(person·year)]	GDP (PPP) [US$2009/(person·year)]	waste landfilled (without yard waste) [kg/(person·day)]	waste recycled [kg/(person·day)]	Recycling rate [%]	waste generated (without public cleaning) [kg/(person·day)]	Total waste generated (including public cleaning) [Mg/year]
2009*	9,488	15,325	0.95	0.21	16%	1.17	3,254,078
2010	9,674	14,708	0.94	0.20	16%	1.14	3,207,309
2011	9,876	15,014	0.94	0.21	16%	1.15	3,271,245
2012	10,082	15,328	0.95	0.21	16%	1.17	3,336,581
2013	10,293	15,649	0.96	0.22	17%	1.18	3,403,349
2014	10,510	15,978	0.97	0.23	17%	1.20	3,471,585
2015	10,951	16,648	0.98	0.25	18%	1.23	3,583,102
2016	11,424	17,369	0.99	0.27	19%	1.26	3,697,372
2017	11,919	18,121	1.01	0.29	20%	1.30	3,815,911
2018	12,436	18,907	1.03	0.31	21%	1.34	3,938,895
2019	12,976	19,728	1.04	0.33	22%	1.37	4,066,520
2020	13,540	20,586	1.06	0.35	23%	1.41	4,198,979
2021	14,129	21,480	1.07	0.38	24%	1.45	4,336,584
2022	14,742	22,413	1.09	0.40	25%	1.49	4,479,519
2023	15,383	23,387	1.11	0.43	26%	1.54	4,628,017
2024	16,051	24,403	1.12	0.46	27%	1.58	4,782,317
2025	16,609	25,252	1.14	0.48	27%	1.62	4,916,014
2026	17,187	26,130	1.15	0.50	28%	1.65	5,054,074
2027	17,784	27,038	1.17	0.52	29%	1.69	5,196,654
2028	18,403	27,978	1.18	0.55	30%	1.73	5,343,920
2029	19,043	28,951	1.20	0.58	30%	1.77	5,496,039
2030	19,705	29,958	1.21	0.60	31%	1.81	5,653,188

* Data for 2009 is taken from the International Monetary Fund. From 2010 onwards, annual growing based on the RHM – BAU scenario is used

Table C.3 Projected waste generated in the CR scenario

Year	GDP [US$2009/ (person·year)]	Waste generated only GDP function (without yard waste) [kg/(person·day)]	Household income	Urbanization	Household size	Education	Waste generated [kg/(person·day)]	Total waste generated (including public cleaning) [Mg/year]
			Change respect to BAU [%]					
2009*	15,325							
2010	14,708	1.14					1.14	3,207,309
2011	15,032							
2012	15,362							
2013	15,700							
2014	16,045							
2015	16,700	1.23	99.0	98.7	100.9	99.5	1.21	3,508,456
2016	17,372							
2017	18,072							
2018	18,800							
2019	19,557							
2020	20,325	1.40	99.0	99.3	98.2	99.6	1.35	4,024,135
2021	21,243							
2022	22,204							
2023	23,207							
2024	24,256							
2025	25,086	1.61	99.0	98.5	96.1	99.5	1.50	4,498,876
2026	25,980							
2027	26,905							
2028	27,864							
2029	28,857							
2030	29,885	1.81	98.1	97.5	96.0	99.3	1.65	4,943,948

Table C.4 Projected waste generated in MI scenario

Year	GDP [US$2009/ (person·year)]	Waste generated only GDP function (without yard waste) [kg/(person·day)]	Household income	Urbanization	Household size	Education	Waste generated [kg/(person·day)]	Waste generated [Mg/year]
			Change in respect to BAU [%]					
2009*	15,325							
2010	14,708	1.14					1.14	3,207,309
2011	14,980							
2012	15,256							
2013	15,538							
2014	15,824							
2015	16,445	1.22	97.9	100.7	100.0	100.5	1.21	3,571,067
2016	17,138							
2017	17,859							
2018	18,611							
2019	19,395							
2020	20,231	1.40	98.0	100.4	101.8	100.4	1.40	4,246,195
2021	21,127							
2022	22,063							
2023	23,040							
2024	24,060							
2025	25,150	1.61	98.0	100.4	101.9	100.5	1.63	5,031,703
2026	26,235							
2027	27,368							
2028	28,550							
2029	29,783							
2030	30,803	1.85	97.1	100.7	104.0	100.7	1.89	6,063,621

Annex D

Landfill Gas Emissions

Table D.23. Landfill gas in MRS 2001-2010

Year	MSW [Mg/year]	MSW total [Mg]	Landfill gas [Nm³/Mg]	Landfill gas [Nm³/Mg/year]	Total landfill gas generation [Nm³/year]
2001	2,227,019				
2002	2,223,849	2,227,019	16.0	16.0	35,585,141
2003	2,289,603	4,450,868	31.2	15.3	69,518,033
2004	2,326,355	6,740,471	45.8	14.6	102,974,365
2005	2,418,439	9,066,826	59.7	13.9	135,512,168
2006	2,502,391	11,485,265	73.0	13.3	168,056,923
2007	2,511,704	13,987,656	85.7	12.7	200,478,376
2008	2,699,449	19,198,809	97.8	12.1	231,589,435
2009	2,719,572	21,918,381	109.4	11.6	264,300,209
2010	2,708,389	24,626,770	120.5	11.1	295,860,301

Table D.2. GHG emissions from landfills in MRS 2001-2010

Year	GHG emissions produced [Mg CO_{2-eq}]	Collected emissions [Mg CO_{2-eq}]	Net GHG emissions [Mg CO_{2-eq}]
2001			
2002	349,715		349,715
2003	683,193	177,630	505,563
2004	1,011,988	263,117	748,871
2005	1,331,755	346,256	985,499
2006	1,651,591	429,414	1,222,178
2007	1,970,215	512,256	1,457,959
2008	2,275,962	591,750	1,684,212
2009	2,597,429	675,332	1,922,097
2010	2,907,588	746,688	2,160,901

Table D.3 GHG associated with recycling in MRS 2007

	Paper/cardboard	Glass	Metals	Plastics
MSW recycled [Mg/year]	210,000	15,000	158,000	16,000
GHG emissions produced [Mg CO_{2-eq}]	37,800	295	3,400	16,000
Avoided emissions [Mg CO_{2-eq}]	-210,000	-7,000	-323,000	-22,000
Net GHG emissions [Mg CO_{2-eq}]	-172,200	-7,000	-319,000	-6,400

Annex E

Sustainability aspects of integration experiences of the informal waste sector in Latin America

Table E.1 Sustainability aspects of Cooperative "El Ceibo", Argentina

Guideline	Policy Regulatory	Organizational	Technical	Performance
Sparing use of non renewable resources	Legal framework in Buenos Aires facilitates creation of cooperatives An agreement was signed between the cooperative and the city government, to send recyclable materials collected by formal companies to the storehouse of El Ceibo, giving legal security	The formation of the cooperative has not reduced the recycling chain Waste pickers fetch recyclable materials to middlemen	Source separation takes place voluntarily, participation increased due to environmental promoters	Increase of amount of materials recovered and recycled in the municipality
Maintaining the regeneration capacity of natural systems	There is relevant legislation promoting waste minimization	No information	No information	The cooperative does not contribute to minimize waste generation Amount of waste sent to landfills decreased
Development of human and knowledge capital	There is lack of a regulatory framework for responsibilities and division of tasks within the cooperative and with formal actors	Waste pickers received training Creation of environmental conscience within residents	No information	The quality and quantity of the materials to be collected /recycled improved
Minimization of adverse health impacts	No information	There is no training for employees regarding safety and they do not have health insurance	No information	No information
Financial viability	There are no direct ways of costs recovery	Sources of revenue corresponds to donations and direct sale of materials	Dependence on stability of prices markets	Lack of information about degree of cost recovery Income level lower than minimum wage
Guaranty of the possibility of independent existence	Actors are supported by law		The value added to materials is still insufficient due to lack of equipments	Public objections do not occur Negotiation capacity has increased, but is still low

Table E.2 Sustainability aspects of "Recycling Dreams", Argentina

Guideline	Policy Regulatory	Organizational	Technical	Performance
Sparing use of non renewable resources	Legal framework for a integral waste management which promotes recycling	No information	Source separation is voluntary, but extended	Recycling rates increased 10 – 15% after formation of the cooperative [1]
Maintaining the regeneration capacity of natural systems	Existence of a legal framework promoting minimization of waste	No information	No information	Diversion of 360 Mg/a from landfills [2]
Development of human and knowledge capital	Clear division of responsibilities among the workers of the cooperative	Training to pickers in recycling and materials processing, with a define time schedule	No information	Quality of the service given by pickers improved, including a large area of the municipality, with specific routes and collection days and hours
Minimization of adverse health impacts	No information	No information	Provision and use of protective equipment and manual cars	No information
Financial viability	No information	Sources of revenue correspond to sale of materials, which depends on prices' stability	No contribution	Income level increased to US$ 180 per month, but in 2007 it was still below the minimum wage of Argentina (US$ 280/month)
Guaranty of the possibility of independent existence	Actors are supported by law		Storing capacity and materials for further processing is available	There are no public objections or penalizations of actors Negotiation capacity has increased

1: Fundación Noble 2008
2: Veira 2008

Table E.3 Sustainability aspects of "ASMARE", Brazil

Guideline	Policy/ Regulatory	Organizational	Technical	Performance
Sparing use of non renewable resources	Municipal regulation gives collection of segregated recyclables to waste pickers' organizations It incorporates source segregation and recycling, it articulates actions with the organizations of waste pickers, through the "Voluntary Collection Points"	Materials are fetched to middlemen and industries, decreasing the recycling chain	Source separation takes places extensively	The recycling rate of Belo Horizonte, was at the time of the assessment 9% thanks to the formation of the association
Maintaining the regeneration capacity of natural systems	No contribution	No contribution	No information	Diversion of waste sent to landfills through increase recycling
Development of human and knowledge capital	There is a framework for the tasks' division and responsibilities within the cooperative	Waste collectors were instructed There is cooperation with the communities and promotion of other collectors associations Courses are offered to people living at the streets	There is supervision and monitoring of the project and of the work carried out Improvements at the technical, social and educational aspects	Increase in domiciliary waste collection from 65% in 1993 to 91% in 1997
Minimization of adverse health impacts	No information	No information	Provision and use of protective equipment	Living conditions were improved because collectors do not longer live on the streets
Financial viability	There is an agreement between the association and the municipality, which has to pay for the services offered	There are subsidies given by the City Hall and collaboration of other organizations which help to pay other expenses Source of revenue correspond to direct sale of materials Buyers of materials are reliable, because of the long operation period of ASMARE	The collectors receive a monthly income according to the volume of collected materials The association establishes a flat price, which the worker receives even if the material is not sold; there are additionally benefits according to productivity at the end of the year	The municipality subsidizes 42% of total income, 10% is obtained through collaboration of external sources, commercialization represents less than 50%, amount enough to pay the salary of collectors 54% earned the equivalent to two minimum salaries, 40% earn between two and four salaries

Table E.3 Sustainability aspects of "ASMARE" (continuation)

Guideline	Policy/ Regulatory	Organizational	Technical	Performance
Guaranty of the possibility of independent existence	Actors are supported and recognized by law		High storing capacity and further processing of materials take place	Negotiation capacity has increased because they are able to deliver materials of good quality, improving their value There are no longer public objection or penalization from public authorities

Table E.4 Sustainability aspects of Association of Collectors of Dois Irmaos, Brazil

Guideline	Policy/ Regulatory	Organizational	Technical	Performance
Sparing use of non renewable resources	Existence of an innovative public politic, promoting recycling	The recycling chain decreased: waste collectors can directly negotiate with production companies, thanks to the better quality of materials delivered, making the system more reliable	Source separation takes places extensively	The recycling rate increased to 18% after formation of the association
Maintaining the regeneration capacity of natural systems	No contribution	No contribution	The municipality is in charged of transporting refuse materials from the recovery facility to appropriate disposal sites	Diversion of waste sent to landfills through increase recycling
Development of human and knowledge capital	Existence of a legal framework for the division of responsibilities of the waste management in the city	Information campaigns to citizens take place	No information	Quality of the MSW management service improved Quality of commercialized products increased
Minimization of adverse health impacts	No information	No information	Provision of protective equipment	Hazards exposure is reduced because workers do not collect materials at the streets
Financial viability	There is a contract between the association and the municipality, additional financial support was given by the National Fond of Environment	Sources of revenue correspond to the subsidy from the municipality, payments for received services and the direct sale of the materials	Monthly payments from the municipality takes place	There is no information about costs recovery degree; however income from commercialization represents 88% of the total
Guaranty of the possibility of independent existence	No information	Negotiation capacity has improved, pickers are able to deliver materials of better quality	Total inclusion of the waste pickers in the formal waste management system	There are no public objections Householders collaborate with source separation, alliances exist with the municipality Salary of workers was above minimum national salary of Brazil at the time of the research

Table E.5 Sustainability aspects of “Paracatu Recycles”, Brazil

Guideline	Policy/ Regulatory	Organizational	Technical	Performance
Sparing use of non renewable resources	Lack of regulatory framework	Direct relation between the association and one plastic company, reducing therefore the necessity of middlemen	There is no source separation, which is a negative aspect	No information
Maintaining the regeneration capacity of natural systems	No contribution	No contribution	No contribution	No contribution
Development of human and knowledge capital	No information	No information	No information	No information
Minimization of adverse health impacts	No information	No information	No information	Improvement, because waste collectors are not working any longer at the dumping site, which decrease their exposure to negative impacts on health
Financial viability	No information	Source of revenue is the sale of materials to middlemen and one plastic company	No information	No information
Guaranty of the possibility of independent existence	Waste collectors are not legally recognized and their “formalization” consisted on changing their working place from the landfill to the streets and storehouse	Their negotiation capacity has improved, because they are now able to deliver materials of better quality, than if they were still working at the landfill	They have equipments to process the recyclable materials	There are no public objections or harassing Their monthly income was below the minimum national, but the association was going through reformation processes that may make possible to increase their income

Table E.6 Sustainability aspects of "Procicla", Paraguay

Guideline	Policy/ Regulatory	Organizational	Technical	Performance
Sparing use of non renewable resources	No information	The length of trading decreased, materials are directly sold to recycling companies	Source segregation takes place voluntarily, participation is not very high, but the fact that it is promoted represents a positive impact	The general performance of the cooperation is positive, because more materials and of better quality are collected by segregated collection than direct at the landfill
Maintaining the regeneration capacity of natural systems	No contribution	No contribution	No contribution	As direct consequence of increase recycling, less waste is sent to final disposal sites
Development of human and knowledge capital	Existence of a framework which specifies the activities and responsibilities carried out by waste pickers	There is training to waste collectors concerning recyclable materials, recycling methods and internships at companies Other courses include legal aspects of formalization	There are volunteers working as environmental promoters to give information to the citizens, institutions or schools, regarding the importance of appropriate waste management and source segregation	Recyclable materials delivered to companies are of better quality than those extracted directly at the landfill
Minimization of adverse health impacts	No information	Training regarding safety	Provision of protective and working equipments	The exposure of collectors has decreased in relation to their exposure to diseases born bacteria and to toxic waste
Financial viability	No information	The source of revenue is the direct sale of materials	Alliances with private companies assure certain degree of revenue	Cost recovery is still insufficient, hence it is difficult to expand commercial operations and increase materials value
Guaranty of the possibility of independent existence	No information	Increase of the negotiation capacity of pickers	Increasing of storing and materials processing	There are no public objections or harassing Income increased from about $5 50 to $8 50 per day, while the average work day has decreased from 12 hours to 8 hours

Table E .7 Sustainability aspects of "Association of Recyclers of Bogota", Colombia

Guideline	Policy/ Regulatory	Organizational	Technical	Performance
Sparing use of non renewable resources	Existence of a law establishing the participation of waste pickers in negotiations of waste management Existence of incentives towards recycling	Decreasing of recycling chain Waste pickers are able to collect larger volumes and able to sell direct to production companies	Source segregation takes place voluntarily and it is promoted	The general performance has been positive, the formation of ARB allowed to increase the recycling rate in Bogotá in 10%
Maintaining the regeneration capacity of natural systems	The efforts carried out by the ARB contributed with the development of local and national laws related with public services and with the structure of waste taxes	No contribution	No contribution	As direct consequence of rising recycling, less waste is sent to final disposal sites Reduction of the total waste generated
Development of human and knowledge capital	Existence of a framework for organization and division of tasks between the actors, including waste pickers This framework includes commercialization and recycling plans and strategies in order to improve the management of waste in the future	Waste pickers have received technical training on recyclable materials and their processing Communities and private companies have also been informed about importance of recycling	Monitoring of the activities carried out by the association takes place	Positive impacts at the social, technical and political level of the services offered; for instance in May 2008 an International Congress of Waste Pickers was organized in Bogota by the ARB
Minimization of adverse health impacts	No information	Training in health aspects of waste management and safety	No information	No information
Financial viability	No information	Source of revenue corresponds to direct sale of materials, however there is no information about the reliability of the buyers or about the revenue collecting methods	No information	Regarding performance, information is scarce; however it is mention that after 2003, costs recoveries improved thanks to improvements in the commercialization capacity of waste collectors
Guaranty of the possibility of independent existence	New plans at district level have started to consider waste pickers as important actors of the waste management	Provision of equipment and use of appropriate technologies Increase in negotiation capacity of the pickers, they are able to collect larger volumes, obtaining better prices	Social security is available, given more security to the employment	Income of waste pickers has increased in 30%

Table E .8 Sustainability aspects of "Recuperar", Colombia

Guideline	Policy/ Regulatory	Organizational	Technical	Performance
Sparing use of non renewable resources	Recycling and recovery of materials is included within the public policy of Medellin There are incentives carried out by the municipality towards source separation and delivery to the waste collectors, which are legally recognized	The length of the trading chain has been reduced with formation of stocking centers operated directly by waste pickers	Source separation takes place voluntarily	Thanks to awareness campaigns, extension of collection routes and source separation, the performance has been positive, increasing amount of materials to be recycled
Maintaining the regeneration capacity of natural systems	There are incentives to minimization of waste production	No contribution	No contribution	There is a large collection of materials to be recycled, that otherwise would be sent to landfills
Development of human and knowledge capital	Existence of a legal framework for coordination of activities and actors' responsibilities, established in the public policy Each cooperative has a framework for the assignment of activities and responsibilities of cooperative members	Waste pickers received training on social, technical and legal issues They received preparation from recycling companies, regarding recycling processes and commercialization of materials There are also, training to householders and companies regarding adequate waste management	Monitoring of the activities of the cooperative Recuperar takes places at the different branches located in Colombia	The performance, regarded as the quality of the service given by waste collectors, increased They cover larger areas of collection and their activities have expanded to other areas, Recuperar is nowadays a very competitive company
Minimization of adverse health impacts	There is lack of information about the labor regulations that the employees should meet, however the public policy of Medellin includes a framework for the management and operation of stock centers	Training in security and health Waste pickers are covered by life and health insurance	Provision of protective equipment The stock center has primary help and fire extinguishers	Reduction of accidents and diseases exposure

Table E.8 Sustainability aspects of "Recuperar" (continuation)

Guideline	Policy/ Regulatory	Organizational	Technical	Performance
Financial viability	No information	Ways of costs recovery include direct sale of materials to production companies and payment for services offered During the first five years of the project a private company collaborated with capital, to finance operation of Recuperar Nowadays, members of the cooperative have access to credits and their activities have expanded in a way that they have reliable suppliers as well as buyers	Revenue collecting methods are done by contracts	The company is economically self sufficient
Guaranty of the possibility of independent existence	Waste collectors are legally recognized and included into formal waste management plans	Negotiation capacity of the workers increased, different materials are commercialized, expanding business possibilities Expansion to other areas outside waste management Workers have social security and a long term perspective job	Waste pickers have a larger storing and materials processing capacity, achieving quality required by production companies	The income level of the waste collectors increase in 50% and there are no penalizations or harassing to them

Table E 9 Sustainability aspects of AREILS, Chile

Guideline	Policy/ Regulatory	Organizational	Technical	Performance
Sparing use of non renewable resources	Existence of an agreement between the municipality, AREILS and CONAMA, aiming to promote recycling and inclusion of waste pickers in formal systems	Reduction of recycling chain, in particular for paper and cardboard, because a direct alliance between AREILS and a paper recovery company (Recupac) exists	There is no source separation at household level, only at the level of large waste producers Potential markets for other recyclable materials exists	Increase of the volume of materials recovered in 30% - 40%
Maintaining the regeneration capacity of natural systems	No contribution	No contribution	No contribution	As direct consequence of larger recycling, less waste is sent to final disposal sites
Development of human and knowledge capital	Existence of a legal framework for the distribution of tasks and responsibilities within AREILS, established in its creation contract	Training of waste collectors has taken place; courses include alphabetization, environmental conscience, commercialization and administration	AREILS belongs to the National Association of Independent Collectors (ASRI), for this reason monitoring of their activities takes place	The quality of the service provided by waste pickers improved in such a way that they became a very important actor in the waste recycling of La Serena and a strong competitor for the largest paper recovery company in the region
Minimization of adverse health impacts	Lack of regulations to be meet by the collectors, but there is a sanitary regulation for the storehouse where separation of materials take place	Waste collectors lack health and social insurance, which is a negative aspect	Training regarding safety regulations Collectors received uniforms and tricycles to carry out their activities	It is not possible to assess the number of accidents and diseases occur to workers, but at least their exposure has decrease because they do not store the materials at the river's bank or at their houses
Financial viability	A legal contract exists with a paper collection company who is in charge of the administration of the stock center	Ways of cost recovery are given by subsidies and sale of materials Financial support was given by the municipality, and other national institutions The main revenue source is the sale of paper and cardboard to a paper company (Recupac), which also pays the maintenance of the stock center	The agreement with Recupac guarantees a constant supply of paper from other non – organized waste collectors and large waste generators, like supermarkets	Degree of costs recovery depends on stability of prices, but the alliance with Recupac has relieved the pressure of waste collectors regarding their expenses

Table E 9 Continuation Sustainability aspects of AREILS, Chile

Guideline	Policy/ Regulatory	Organizational	Technical	Performance
Guaranty of the possibility of independent existence, which fulfils the basic needs and creates opportunities for development	Existence of an agreement recognizing and supporting the activities of the waste collectors, who should also receive a municipal license to formalize their job	Their negotiation capacity improved largely because they are able to collect more materials of better quality Their employment security has also improved, thanks to the contract with Recupac and the project has a long term perspective	Use of stock center and equipment to process the materials	There are no public objections or harassing; and even though the income of pickers was at the moment of the evaluation below the national minimum, it increased about 8% after the formation of AREILS