# TOWARDS CIRCULAR ECONOMY IN DEVELOPING CITIES

## AN INTEGRATED APPROACH FOR PLANNING INTERNATIONAL COOPERATION PROJECTS


Eng. Navarro Ferronato
Ph.D. student

*University of Insubria*
*Department of Theoretical and Applied Sciences*



Ph.D. course in Environmental Sciences
$32^{nd}$ cycle (2016 - 2019)


Supervisor
Prof. Eng. Vincenzo Torretta

*- Be the change that you want see in the world -*
*M. Gandhi*

# Contents

# Abstract

Solid waste management (SWM) issues are an environmental and social burden, which affect mainly the population of low-middle income countries worldwide, as well as the global environment. The introduction of sustainable and integrated SWM systems is compulsory for improving sustainability at global level. The application of the circular economy (CE) principles (reuse of waste materials) is considered the main solution for reducing the use of raw materials and energy, in order to spread the economy of the waste, improving the social inclusion, environmental sustainability and economic resilience. The active role of Universities and Non-Governmental Organizations (NGO), among other international stakeholders and funders, is imperative for starting environmental and social projects for introducing actions towards sustainable development in areas with low financial and technical availability.

This research is focused on the analysis and application of the methodological approaches for introducing the CE in developing cities, where the lack of know-how, regulations, social acceptance, political will and the constant increase in environmental impacts reduce the hope of success in implementing sustainable SWM systems. The objectives of the research are: (1) Provide an integrated approach for planning sustainable SWM systems in developing big cities of Latin America; (2) Demonstrate the importance of the inclusion of the informal recycling in the formal SWM system for improving waste recovery; (3) Draft an international cooperation project for introducing new appropriate technologies and sensitivity campaigns for boosting CE.

The case study of this research is La Paz (Bolivia), low-middle income city where international support is required for starting CE projects. The research is divided in four main parts: (1) first assessment of the municipal SWM system of the city and statement of the problem, (2) analysis of potential future scenarios, (3) analysis and implementation of tools and methods for SWM planning, and (4) proposal and submission of international cooperation projects. The first three steps are implemented according to technical and scientific approaches that allow supporting the finding of the research, while the last point is the consequence of the approaches and studies introduced.

The results allow suggesting that La Paz is under development for implementing sustainable SWM systems and it is quite developed if compared with other cities located in similar low-income contexts. The inclusion of waste pickers and informal recyclers can be considered the most useful option in terms of technical and financial issues, exploiting a CE system just in place. The population is ready for starting take back programs and selective collection activities, since more than 50% of the population is just used to implement the separate collection at home, providing the separate materials mainly to the informal sector. At the same time, the implementation of recycling activities allows obtaining preliminary good results in terms of citizens involvement and selective collection rate, suggesting that information campaigns and

apporpriate infrastructures are the main requirements for obtaining good results in La Paz. Moreover, the inclusion of the waste pickers allows reducing about 10% of the management costs, if compared with a complete SWM system, while environmental impacts are always reduced thanks to recycling. The main issues are: how the waste pickers can be included? Where financial support can be obtained? How technical knowledge can be shared? The same issues were found in the management of health-care waste (produced in hospitals), showing that municipal solid waste is not the only fraction that should be managed properly.

These findings, as well as the cooperation with local and international stakeholders, allow writing and submitting two international cooperation projects. The first submitted to the Italian Agency for Development Cooperation, while the second submitted to the European Commission. The proposals used the methods, findings and collaboration started thanks to the Ph.D. research. The project submitted to the Italian Agency was approved and financed in June 2019. It started the 2nd of September, for supporting the implementation of recycling activities in La Paz. The second project is about the inclusion of young innovators and the waste pickers for starting CE plans taking into account local knowledge, activities and markets. It passes the first step review, although it has not been approved at the final stage of review due to the low experience level of the Bolivian NGO for the management of financial resources.

In conclusion, the studies implemented in this Ph.D. research can be the baseline for building proposals that can be submitted for obtaining international funds, in order to introduce treatment plants, to use planning tools, to improve technical knowledge and to increase social acceptance in SWM systems of low-income areas. Moreover, the same research can be replicated and applied in similar developing cities where simple and effective solutions should be found in short terms, supported by technical approaches. The research demonstrates that the cooperation among various international and local actors, such as Universities, NGO and local Government, in parallel with the use of technical knowledge and methodologies can support the sustainable development in low-middle countries, driving low-middle income cities towards the CE.

# Acknowledgement

I would like to thank my supervisors, Prof. Vincenzo Torretta and Prof. Marco Ragazzi, for their support in this long journey. They were the first that believed in my capacities and willingness. Thanks to my supervisors in Bolivia, Prof. Marcelo Gorritty and Prof. Gabriela Guisbert since without their effort and support my whole research could not be implemented. At the same time, thanks to Eng. Farina Flores and the whole Municipal Secretary for Environmental Management of La Paz, who supported my research providing me the opportunity to work with them. Thanks to Doc. Roberto Cavallini, country coordinator of the NGO COOPI, that trusted in my ideas and provided me the opportunity to support their NGO. Thanks to Don Antonio Ferronato, the real maker of this international cooperation teamwork. The Ph.D. research was supported by a Global Grant of the Rotary Foundation (GG1758711 Scholarship) provided by the District 2060, the Clubs Rotary Bassano del Grappa Castelli and Rotary La Paz Sopocachi. Thanks to all the Rotary members that supported this research fellow, in particular Mr. Bruno Bertacco and Mr. Mario Patuzzi. Thanks to Gianluza Preziosi and Marisol Torrez, the students that supported my research in GIS and healthcare waste management, respectively, and many thanks to all the volunteers that supported the research and the actions that I developed in La Paz during my stay. Finally, a huge thank you to Anna Maria, my bright star, and to my family, for their support and for understanding my distance and absence during my long period of stay in Bolivia. Here, in this work, I enclose my dreams for a sustainable future: I hope that it could be useful for the current and future generations.

# Nomenclature

| Acronym | Description |
|---|---|
| 3Rs | Reduce-reuse-recycle |
| AD | Anaerobic digestion |
| AICS | Italian agency for development cooperation |
| AP | Acidification potential |
| BC | Black carbon |
| C&DW | Construction & demolition waste |
| CE | Circular economy |
| CHP | Combined heat and power |
| CI | Confidence interval |
| COOPI | Cooperazione internazionale |
| CRIC | Construction resource initiatives council |
| DtD | Door to door |
| EC | European commission |
| EEA | Environmental European agency |
| ELV | End of life vehicles |
| EP | Eutrophication potential |
| EPR | Extended producer responsibility |
| EU | European union |
| GAMLP | Municipal autonomous government of La Paz |
| GHG | Green-house gas |
| GIS | Geographic information systems |
| GNI | Gross national income |
| GP | Green points |

| | |
|---|---|
| GWP | Global warming potential |
| HTP | human toxicity potential |
| HW | Healthcare waste |
| HWM | Healthcare waste management |
| ISWA | International solid waste association |
| LCA | Life cycle assessment |
| LCIA | Life cycle impact assessment |
| LCI | Life cycle inventory |
| LFGCE | Landfill gas collection efficiency |
| MBT | Mechanical biological treatment |
| MCDA | Multi-criteria decision analysis |
| MSWM | Municipal solid waste management |
| MSW | Municipal solid waste |
| NGOs | Non-governmental organizations |
| OFMSW | Organic fraction municipal solid waste |
| PAH | poly-aromatic hydrocarbon |
| PPE | Personal protective equipment |
| PPP | Public private partnership |
| RDF | Refuse derived fuel |
| RP | Recycling policies |
| RR | Recycling rate |
| SAW | Simple additive weighting method |
| SC | Selective collection |
| SCS | Selective collection systems |
| SDGs | Sustainable development goals |
| SRM | Secondary raw materials |
| SSC | Separate street containers |
| SRF | Solid recovered fuel |
| SWM | Solid waste management |
| TOC | Total organic carbon |

| | |
|---|---|
| UNDP | United nation development program |
| VOC | Volatile organic compounds |
| WBI | Wasteaware benchmark indicators |
| WEEE | Waste electrical and electronic equipment |
| WFA | Waste flow analysis |
| WHO | World health organization |
| WRATE | Waste and resources assessment tool for the environment |
| WtE | Waste to energy |

# Introduction

Globally, an average person generates about 435 kg of municipal solid waste (MSW) per year, with about 50 kg of recyclable materials (paper, plastic, metal, glass) that can be potentially substitute the demand of virgin materials [1]. These amounts vary among low-income and high-income countries. For example, in Kenya, the generation per capita is about $110\,kg\,y^{-1}$, in China $229\,kg\,y^{-1}$, in Mexico $343\,kg\,y^{-1}$, achieving $450\,kg\,y^{-1}$ in Spain and $777\,kg\,y^{-1}$ in Canada [2]. The current annual MSW generation is estimated to 1.9 billion tonnes. Almost 30% is uncollected, while 70% of the collected is disposed of to landfills and dumpsites, only 19% is recycled or recovered and 11% is converted to energy. To date, worldwide, the number of people that lacks access to elementary waste management services is estimated to 3.5 billion [2].

Through recycling, the ‘zero waste activity’ is encouraged and an average person could save around 216 kWh of energy, 0.05 kg of green-house gas (GHG) and 36L of processed water. In this way, it has been calculated that each person would potentially save about 61.3 USD annually, of which 17 USD derived from materials substitution, and 44 USD from energy substitution [1]. Moreover, it has been estimated that the appropriate management of solid waste allows reducing the global warming potential (GWP) for about 3%, while the sustainable use of the resources contributes its reduction for at least 20% [3]. However, waste management is still a global challenge, also in this century, both in developed and developing countries [4]; therefore solutions should be applied involving all the stakeholders interested in such practice.

The main issues for improving the solid waste management (SWM) are detected in developing countries, where the lack of financial support, regulation, appropriate technologies, political will, public awareness and know-how makes the improvement of SWM a real challenge [5]. These difficulties improves the environmental contamination at global level due to the open dumping and open burning of solid waste, which are common practices in the developing world [6]. Indeed, the main source of GHG and leachate, influencing the global warming and the contamination of water bodies, is due to the open dumping of the organic waste fraction and the uncontrolled combustion of hazardous and municipal solid waste (MSW) [3]. So, the implementation of sustainable SWM in developing countries is compulsory for improving environmental sustainability at global level.

The Circular Economy (CE) is seen as the main solution for boosting the principle of the ’zero waste’. The main idea is to change the principle of produce-use-waste of goods with the reduce-reuse-recycle (3Rs) principle, using the waste as resource for the products of tomorrow [7].The principle of the CE were introduced in Europe in 2018, with the first CE package implemented for spreading the recycling of plastic materials, reducing the waste to sanitary landfill and reducing the food waste in order to improve sustainability [8]. CE would emulate the environment, redesigning the production of goods, optimizing natural resources use towards a closed cycles of materials and energy (circularity), reducing the generation of waste [9]. Therefore, CE is based on three main objectives [10]:

- First, a CE aims to reduce waste since products are designed for a cycle of disassembly and reuse.
- Second, circularity introduces a strict differentiation between consumable and durable components of a product, boosting the use of biological ingredients that can safely be returned to the biosphere, while inorganic are designed from the start for reuse.
- Third, the energy required should be renewable, again decreasing resource dependence and increase systems resilience

At global level, the principle of the CE were introduced within the Sustainable Development Goals (SDGs) developed by the United Nations. In particular, objective 12 - Ensure sustainable consumption and production patterns - advise to improve the sustainable consumption of materials, energy and food, reducing the amounts of waste and reusing the waste produced [11]. Emphasis is given to the developing world, with specific targets for ensuring the sustainable improvement of the population standard of life also in low-middle income countries. An example is provided by indicator 12.a - Help developing countries strengthen their scientific and technological capacity to move towards more sustainable modes of consumption and production - .

Within the scientific literature, Chinese and European scholars reported many studies and experiences about the implementation of CE, although at its early stage [12], while in developing countries, considered as low, low-middle and middle income countries according to the classification of the World Bank, the CE is not still investigated and implemented [9]. In developing countries, the CE is mainly introduced by the informal recycling sector, represented by families with low-income level that recover recyclable materials for selling it to the local recycling market [13]. The recycling rates achieved is not comparable with modern systems; however, this sector saves the city authorities financial resources avoiding waste collection and disposal costs [14].

Bolivia is a low-middle country where the informal recycling sector live within cities and towns and where the environmental contamination due to SWM is a big issue. Indeed, the open burning of MSW, the uncontrolled disposal of hazardous waste, the lack of waste collection and the release of leachate to the waster bodies are only a few activities that pollutes the environment, affecting the health of the population. Some pilot project were introduced in the last decade for introducing the CE principles, although with no effective results. Moreover, the theme of SWM is still under development and the country lacks the implementation of effective solutions.

The aim of this Ph.D. thesis is to assess the opportunities and challenges for introducing the CE principles in a developing big city of Bolivia as example for improving the quality of the SWM at national level and for other countries of Latin America, where the implementation of recycling schemes are still under development. The approach starts with the analysis of the problem at global, national and municipal level, suggesting feasible CE scenarios. Then, the study introduces and analyzes the application of planning tools suited for a developing context. Moreover, the research investigates the social behavior in recycling activities, environmental impacts of MSWM scenarios, and the pros and cons of the implementation of a selective collection (SC) system in urban areas. Finally, the study provides an example of the implementation of the planning tools used in this research for an international cooperation project started thanks to the implementation of this Ph.D. research.

The document is divided in five main chapters. In the first chapter the study area, the stakeholders involved, the aim and scope of the thesis and the overview of the methods used are introduced. The second chapter contains the SWM issues typical of developing countries and the ones detected in the case study, comparing opportunities and challenges for introducing the CE principles in La Paz and other developing cities. The third part of the thesis develops the CE models which could be theoretically implemented in developing countries and within the case study, compared with other scenarios that could be implemented in the context by a multi-criteria decision analysis (MCDA) and a preliminary quantitative assessment of the GWP, material recycling and cost savings. Chapter four introduced the methods used for assessing the feasibility of the implementation of a CE system in the city by a social survey, method used for assessing the social behavior about the SC of MSW, the introduction of a SC pilot plan at the University, for demonstrating which challenges are typical for introducing the system in public areas, the assessment of the environmental impacts by a Life Cycle Assessment (LCA) of the scenarios introduced in Chapter three, the use of geographic information systems (GIS) for assessing the feasibility of implementing SC within the city, and finally the application an indicator set introduced for analyzing the healthcare waste management (HWM), implemented for assessing the main issues for improving the system and reducing the environmental and operational problems at the sanitary landfill. Finally, Chapter five explains the international cooperation projects drafted and submitted thanks to all the steps reported in the previous chapters. Conclusions and future perspectives are reported in the last part of the thesis.

The research is a path started from a Msc degree thesis on Environmental Engineering, where a network of stakeholders and actors has been built in order to start an international cooperation process. The Ph.D. research was implemented after an accurate assessment of local SWM issues and potentialities in order to understand how the SWM system can be improved and which technologies are most suited for the context. The study ends with the drafting, submission of two international cooperation projects wrote with four different partners and submitted to the Italian Agency for Development Cooperation (AICS) and to the European Commission (EC). The novelty of this research is the implementation of various management and assessment tools about MSWM for providing an integrated frameworks of a developing city, in order to obtain financial resources for starting sustainable and integrated MSWM pilot projects, taking into account local opportunities (i.e. informal recycling) and challenges. Therefore, this Ph.D. study is an example about the feasibility to start integrated international cooperation projects about the implementation of SWM plans starting from zero, with two main requirements: the aid of national and international Universities, Non-Governmental organizations (NGOs), private companies and the local Government; and the continuity of the research.

# Bibliography


[1] Zaman, A. U., and Swapan, M. S. H. (2016). Performance evaluation and benchmarking of global waste management systems. Resources, Conservation and Recycling, 114, 32-41.

[2] Waste Atlas. http://www.atlas.d-waste.com/. Waste Atlas is an online database, produced in collaboration between D-Waste, ISWA, Waste to Energy Research and Technology Council (WtERT), Solid Waste Exchange of Information and Expertise Network (SWEEP-Net), the Society of Solid Waste Management Experts in Asia and Pacific Islands (SWAPI), and the University of Leeds.

[3] Wilson, D. C., Rodic, L., Modak, P., Soos, R., Carpintero, A., Velis, K., ... and Simonett, O. (2015). Global waste management outlook. UNEP.

[4] Wilson, D. C. and Velis, C. A. (2015). Waste management–still a global challenge in the 21st century: An evidence-based call for action.

[5] Guerrero, L. A., Maas, G., and Hogland, W. (2013). Solid waste management challenges for cities in developing countries. Waste management, 33(1), 220-232.

[6] Zhang, T., Fiedler, H., Yu, G., Ochoa, G. S., Carroll Jr, W. F., Gullett, B. K., ... and Touati, A. (2011). Emissions of unintentional persistent organic pollutants from open burning of municipal solid waste from developing countries. Chemosphere, 84(7), 994-1001.

[7] Stahel, W. R. (2016). The circular economy. Nature News, 531(7595), 435.

[8] EPRS - European Parliamentary Research Service (2018). Circular economy package: Four legislative proposals on waste. Members' Research Service. PE 614.766.

[9] Ghisellini, P., Cialani, C.,& Ulgiati, S. (2016). A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. Journal of Cleaner production, 114, 11-32.

[10] Ellen MacArthur Foundation and McKinsey & Company (2014). Towards the Circular Economy: Accelerating the scale-up across global supply chains. World Economic Forum, Geneva, Switzerland.

[11] United Nations. (2015). Transforming our world: The 2030 agenda for sustainable development. A/RES/70/1. sustainabledevelopment.un.org

[12] Geissdoerfer, M., Savaget, P., Bocken, N. M., & Hultink, E. J. (2017). The Circular Economy–A new sustainability paradigm?. Journal of cleaner production, 143, 757-768.

[13] Wilson, D. C., Velis, C., & Cheeseman, C. (2006). Role of informal sector recycling in waste management in developing countries. Habitat international, 30(4), 797-808.

[14] Wilson, D. C., Rodic, L., Scheinberg, A., Velis, C. A., and Alabaster, G. (2012). Comparative analysis of solid waste management in 20 cities. Waste Management & Research, 30(3), 237-254.

# Chapter 1

# Research outline: Study area, objectives and actors involved

*- It is right to save the humanity, it is wrong to pollute this earth,*
*it is right to give hope to the future generations -*
*Al Gore (An inconvenient sequel, 2019)*

## Introduction

In this chapter, the baseline information of the research are provided, in order to introduce the study area and the country where the field work took place, the main objectives of the research and the network involved in the international cooperation process. In particular, the first section contains information about the geographical area and the economic state of the country (Bolivia) and the developing city (La Paz) where the research was developed, introducing the SWM system of the country. These information are useful for understanding the main issues detected in the study area and the advantages for introducing a project of international cooperation.

In the second part of the chapter, the aim of the research is introduced, explaining which issues are addressed and specifying what is the reason for the implementation of the research. The third section introduces the stakeholders involved in the research, specifying their role and their support for solving the main issues identified within the study area. Finally, the last section introduces the methods used, the theoretical framework followed for introducing the international cooperation project and the structure of the thesis, for explaining all the theoretical and practical studies implemented.

## 1.1 Study area

### Bolivia and its SWM

The research was implemented in Bolivia, classified by the World Bank (2017) as a low-middle income country (GNI of 3,070 USD per inhabitants) with a population of about 10,500,000 inhabitants [1]. Bolivia is located in the center of the South America continent, with a land extension of 1,098,581 $km^2$ and a population density of about 9.5 inhabitants per $km^2$. Due to the high poverty rate, about 39% of the population, and the low alphabetization, Bolivia is a region of priority for the International Cooperation for developing development projects. For this reason, it has been considered as case study for the Ph.D. study.

Bolivia is divided in nine department with 112 provinces and 327 municipalities. The capital city is Sucre, while the center of the Government is La Paz. At national level, Bolivia presented three levels of government: The central government, the autonomous departmental government and the autonomous municipal government, which are all active in regulation and management controls. This improves difficulties in the implementation of new management plans, especially regarding environmental themes, since the main topics considered referred to the economic development.

At national level, the SWM is in charge of the Deputy Minister of Potable water and Sanitation, by means of the SWM direction agency, responsible of the introduction of new polices and development plans at National level. It has been estimated that in 2010 the generation of solid waste achieved 1,677,650 tons per year, among which 85% were produced within urban areas, while 15% in rural towns [2]. Therefore, the national production of MSW in urban areas was about $0.5\,kg\ inh^{-1}d^{-1}$ while in rural areas was about $0.2\,kg\ inh^{-1}d^{-1}$, with significatn differences among cities, towns and rural communities.

Generally, within the cities, municipal companies provide sanitation services in four different forms: (1) direct management from the municipalities, (2) from an indirect office of the municipality, (3) from public decentralized companies that can be autonomous or (4) private companies engaged by the municipality. In 2010, 51% of the municipalities, which are mostly of little dimensions (2,000 inhabitants), were not provided by sanitation services. Within the cities where SWM is applied, only 17% obtained urban charges, which allow covering 40-60% of the total costs. As a result, this practice influences the financial sustainability of a municipality, which must use important economic resources mostly for the collection of MSW, among the other waste fractions, such as industrial waste, healthcare waste and construction & demolition waste (C&D) [2].

The service covered 86% of the areas in capital cities, 78% of bigger municipalities, 63% of the minor municipalities and 42% of the rural areas. It means that the rest of the solid waste generated is burred, burned or disposed of in open sites, contaminating the soil and water bodies.

It has been estimated that, at national level, only 4.6% of MSW is recovered by the informal and formal recycling sector and introduced within the recycling chain. The informal sector is widespread within the country, since it is a common practice for poor people or households, which can achieve a financial sustainability by sending recyclable materials to an informal sector that is growing in dimension. It has been estimated that around 10,000 people work like informal pickers within the country [2].

Considering that each waste picker can collect more than 100 kg of recyclable waste per week, about 50,000 tons per year of recyclable materials are recovered by the informal sector.

An important role is made by the NGOs that work in the country, both in rural and urbanized areas, and collaborate with different national and international stakeholders. The efforts applied by these groups led to implement new programs that aid the public governments to improve the informal recycling sector and the formal recycling systems. For instance, Swisscontact, with the program "Ecovecindarios" allows the implementation of 378 new jobs and the collection of 15,900 tons of recyclable waste in three years [4, 5].

The worst environmental issue come from final disposal sites, which receive only 45% of solid waste from formal collection systems in the whole country, since only 8% of final disposal sites in Bolivia are sanitary landfills. It means that final disposal is mostly uncontrolled, without environmental monitoring, growing the threat of disease and pollution, as depicted in Figure 1.1 where two photos took in rural areas of Bolivia during the field works are reported.


**Figure 1.1:** Open dump sites of Bolivia manged in rural communities and towns (*source: personal photos took during the field work in 2018*)

Low financial sustainability, technical facilities and management plans do not encourage Bolivian policy-makers to introduce new solutions in order to improve sanitation systems [2]. However, in 2015 the first national law was introduced by the National Government, while in 2016 was introduced the first regulation about SWM. In these documents, some new concepts were introduced, such as the extended producer responsibility (EPR), which has been introduced although it has not been applied yet due to the lack of monitoring and a management system. Some technological improvements are going to be introduced, mostly by the international cooperation and by South American economic aids. Finally, the inclusion of the informal recycling sector is encouraged ant the principle of 3Rs was introduced, that represent a good starting point for a low-middle income country.

As regards the implementation of national targets and objectives, in 2011 the national program for SWM was introduced, where future strategies, projects and goals were announced. For the end of 2015 the objectives were the reduction of the MSW generation index of about 1% in comparison of 2010, improve the operation activity of 15% of the final disposal sites, improve the service covering of 5% at national level, involve the citizens in 15% of the Bolivian municipalities and at the same time improve the technical management within 15% of the cities. This program is carried out by the national policy; however, international economic funds were introduced for an amount of about 62 million USD [3]. To date, there are not public information about the evolution of such indicators, and it is difficult to estimate the current improvement applied within the country.

SWM is still a difficult issue and in continue development while only a few and scattered studies about SWM are available into the scientific literature as well as reliable data. However, the recycling activities applied by the private sector could be a viable way for public MSW management service, since the recyclable materials could be sold to these recycling facilities. Differently by the occidental approach, currently the public management could gain form the sold of recyclable materials, representing an opportunity for the public management. So, municipalities should not pay for its exploitation, and it means that circular economy could be more attractive for municipalities.

**La Paz**

The case study of the research is La Paz, developing big city of Bolivia. La Paz is located in central Bolivia, close to the Andean plateau and the Real Mountain Range. With a high rate of urbanization (estimated at about 1.1%) [7] due to population movements from the rural areas to the big cities, poor political urban planning and lack of waste water treatment, among others environmental and social issues, La Paz is faced with many negative environmental impacts, such as river water pollution, soil contamination and erosion, water scarcity and air contamination.

The city has a population of about 850,000-950,000 inhabitants (data not confirmed but used by local authority offices), which raises to 2,000,000 if added with the nearest El Alto city population: approximately 20% of Bolivia's total population. It should be highlighted that the official information stated that the city of La Paz has a population of about 764,617 [7].

La Paz, being the Government seat, is also one of the most developed and built Bolivian cities, while the absence of free areas leads to city center growing with bulky buildings and skyscrapers, which increase the issues concerning public service provision. The average city altitude (3,600 m a.s.l.), the problematic morphology and the limited area for the expansion of the city combined, means serious difficulties in public services development and regional control. La Paz is located within a multitude of valleys and rifts, with different slopes, which do not allow the introduction of new infrastructures and factories. Moreover, issues regarding urban planning are encouraging the spread of uncontrolled settlements within the external areas which are not provided with public services such as water, sanitation and energy.

Such problems should be considered for evaluating the provision of an efficient MSWM service since there are difficulties in MSW collection and the implementation of new facilities for the treatment and final disposal of waste. For these reasons, management tools, new technologies and affordable plans are needed for facing the environmental contamination due to SWM, which considered the MSW, C&D waste, Healthcare waste management (HWM), hazardous waste, among others.

## 1.2 Aim and scope of the research

The aim of the study is to support the implementation of new projects and activities for improving the SWM system in La Paz. La Paz is considered as the example at national level for introducing innovative systems and plans that can be therefore introduced in other municipalities of Bolivia. For this reason, the implementation of new SWM plans in La Paz means to introduce high impacts changes in Bolivia, boosting the sustainable development at national level.

Due to the physical characteristics of the city, the SWM is very difficult and there are many issues that should be overcome. The most important issue detected by the local Government is the management of the sanitary landfill, one of the biggest and most developed of Bolivia. The sanitary landfill of the city is located within a valley at 15 km far from the city. However, its useful life is estimated at no more than 2 years from 2019, while there is not a plan for starting the implementation of a new final disposal site. The main issue is the location of the site, since La Paz has no free spaces for introducing it. Therefore, the situation imposed to build a new sanitary landfill 40 km far from the city, with high management and transportation costs. In January 2019, the sanitary landfill collapsed due to a landslide that contaminated the whole area and caused the close of the site. New management actions are compulsory for reducing the waste inflow into the final disposal site and for improving the quality of the SWM of the city.

The implementation of new management plans are required for enhancing the MSW recycling rate, for reducing the hazardous waste inflow into the sanitary landfill, and for improving the awareness of the population. New technical suggestions should be introduced by the University, as requested by the Mayor of the city at the end of 2017, and the Ph.D. study, in cooperation with various local and international actors, provided support to this need.

The general objective of the work is the introduction of a CE approach useful for allowing new economic advantages by waste valorization. The main goals are:

- Provide an integrated approach for planning sustainable SWM systems in developing big cities of Latin America.
- Demonstrate the importance of the inclusion of the informal sector in the formal SWM system for improving the recycling activities.
- Draft an international cooperation project for introducing new appropriate technologies and sensitivity campaigns for boosting CE.

These three topics were investigated and introduced by the aid of management tools and field studies, supported by an international cooperation network that allows collecting data, implementing direct analysis and field inspections and introducing direct management plans.

## 1.3 Local and International stakeholders: the cooperation network

The process of International Cooperation started in 2016 with a master degree thesis in environmental engineering. University agreements were signed by two Italian Universities (University of Trento – Department of Civil, Environmental and Mechanical Engineering; University of Insubria - Department of Theoretical and Applied Science) and a Bolivian one (Universidad Mayor de San Andrés – Department of chemical and environmental engineering), in order to develop researches about environmental themes [8].

The subscription of the first agreement occurred in September 2015 by the University of Trento for allowing the first field work about SWM, developed from February to May 2016. Thanks to the good implementation of the study, the Ph.D. research introduced in this thesis led to implementing a second agreement (with University of Insubria) and the work of other three students about wastewater treatment, rain water harvesting and SWM. In particular, the third thesis started at the end of 2018, with a field analysis in La Paz from February to May 2019, and allows supporting the research of the Ph.D. with the analysis of a SC system within the University and the implementation of a study with geographic information systems (GIS).

The local Universities of La Paz were interested in introducing new relations with European Universities, since, over the last years, international NGOs were involved in local development activities and projects for improving environmental sustainability. Moreover, the University of Trento is organized for implementing international cooperation agreements due to a dedicated master degree in environmental engineering for international cooperation. As a result, the international cooperation between scholars of European countries has been viewed as an opportunity for improving the network among the municipal authorities and the NGOs that are operating within the country, and in the city of La Paz. The objective was the introduction of new projects for sustainable development.

Local and Italian Universities started a strong connection thanks to the Ms degree and the Ph.D., allowing the implementation of a field work in La Paz (totally fifteen months) for collecting data and enforcing the cooperation network. Therefore, the actors involved within the international cooperation network cooperates since four years. The Ph.D. thesis covers such period, exploring the SWM improvements introduced within the years and implementing theoretical studies.

The inclusion of the university allows building a report about the current SWM practices of the city, providing suitable information for introducing recycling companies and management tools useful for planning future activities. The work has been developed thanks to the aid of NGOs involved in the SWM of La Paz. In particular, a local NGO (Swisscontat) has been involved during all the field work for its specific knowledge about La Paz SWM and for the interest in introducing new recycling policies. Swisscontact also provided reliable studies about local issues and the activity of the informal recycling sector. Another Italian NGOs, COOPI - Cooperazione Internazionale, was involved for drafting two international cooperation projects wrote in cooperation with the universities and the municipal autonomous government of La Paz (GAMLP). In particular, the projects represent the final stage of the Ph.D. research, since it is the implementation of the whole research introduced during the four years.

For supporting the Ph.D. research in La Paz, an important role is played by The

Rotary international, since provided the economic support to the Ph.D. for spending one year in Bolivia, continuing the implementation of the project, and involving other stakeholders into the study.

The network implemented with the NGOs and the Universities, the preliminary knowledge of the context and the field work, allowed working in direct contact with the GAMLP. The local Government provided the information which were not accessible and confirm some hypothesis that were made. Moreover, it is the actor constantly involved and informed about the results obtained by the studies and the beneficiary of the research and of the project introduced. As a result, these dealings led to start an integrated and multi-stakeholder cooperation for the development of programs about SWM. The international network is schematically reported in Figure 1.2.

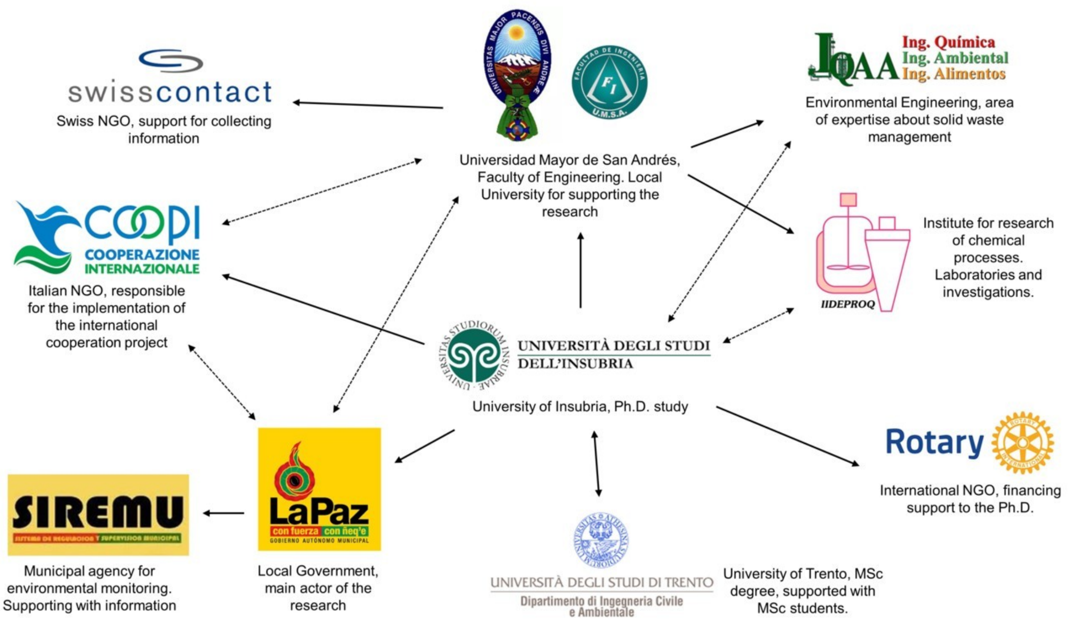


**Figure 1.2:** International cooperation Network of the research.

The university has a central role in developing new researches, holding the contacts with the local government, private companies, NGOs, citizens and mass media. The stakeholder involvement, with a preliminary study of documents and past studies, allowed understanding difficulties, threats and opportunities in La Paz SWM system, finally drafting the international cooperation project.

In conclusion, University of Insubria, through the Ph.D. research, keeps the stakeholders involved in the project. In particular, University of Trento provided the students interested in implementing their thesis in La Paz; the NGOs supported the research providing information and searching for financial support; the local University (Universidad Mayor de San Andrés) supported the work in all its parts, as co-actor in Bolivia, through the expertise in SWM and the availability of research laboratories; finally the local Government, constantly informed about the advances of the work, and SIREMU (Sistema de regulación municipal), as public actor that works in the sanitary landfill and within the environmental monitoring system of the city.

## 1.4 Overview and structure of the thesis

The international cooperation network allows implementing the research for introducing CE plans in the city. Figure 1.3 reports the scheme of the theoretical assessment implemented for analyzing the SWM system of La Paz and the sanitary landfill management. The Figure allows explaining the theory followed for implementing the Ph.D. The approach is composed of three main parts:

- Preliminary assessment
- Advanced assessment and researches implemented during the Ph.D. study
- Impacts of the international cooperation projects started thanks to the Ph.D. research

In the first part, the preliminary assessment is introduced for evaluating the SWM current scenario of La Paz. For supporting the analysis, the wasteaware benchmark indicator (WBI) and the waste flow analysis (WFA) were implemented. These methods are suggested by the International solid waste association (ISWA) and the United Nation Development Program (UNDP) for assessing the SWM of big cities in different income countries. These methods were implemented in many cities worldwide [9], so the case of La Paz can be compared with others. The first field work in La Paz, where the WBI and WFA were implemented, took place in 2016. Therefore, the first analysis and description of the study area is of that year. The analysis is reported within the second Chapter of the thesis, after a narrative literature review about the SWM issues typical of developing countries, in order to compare the results obtained in La Paz with other contexts worldwide. Then, the improvement of the MSWM system during the years and the comparison with other case studies published in 2018 are presented.

The second part of Figure 3 reports the core of the Ph.D. study and the main activities implemented during the three years. In red is reported the main issue that should be solved for the case of La Paz: the management of the sanitary landfill. This represent the main theme that moves the research according to local needs.

The first part of the assessment, after the preliminary study, is the implementation of a multi criteria decision analysis (MCDA) of future management scenarios. This study is reported within the third Chapter of the dissertation, after the assessment of the main waste collection and treatment technologies suited for developing cities and the suggestions of a theoretical CE model for developing cities. This represents the preliminary study for introducing the integrated analysis of the context. The collection and treatment scenarios are then deeply analyzed within the next steps of the research.

Chapter four reported the main analysis introduced within the research. In particular, a social survey was implemented in the city for assessing the social recycling behavior for understanding how the informal recycling sector can be introduced within the formal SWM system. A life cycle assessment (LCA) about the scenarios introduced in Chapter three was implemented for assessing the environmental impacts avoided due to recycling and the inclusion of the informal recycling sector. Moreover, a spacial analysis for assessing how the MSW management (MSWM) scenarios can be introduced in the city were also assessed by the use of GIS. Therefore, an integrated analysis was introduced, assessing the social behavior, environmental impacts and the geographical feasibility of all the scenarios. Finally, a pilot project of SC was implemented within the University (UMSA), where the quantities selected were assessed and where the opinion and knowledge of the students were also analyzed. This experience was of interest since represents the practical issues detected for implementing a SC system in public areas (starting from zero).

At the end of chapter four, the analysis of the HWM system of the city was implemented. It has been introduced by the implementation of new benchmark indicators implemented in this research. The indicators were implemented for detecting main issues and weakness of the HWM system of La Paz, in order to improve the quality of the collection and final disposal system. Finally, the assessment of the informal recycling system was introduced in Figure 1.3 although it has not been implemented thoroughly. Its analysis in introduced in the whole research by integrated approaches, participating in activities for their inclusion. Moreover, it is the main topic of the second project submitted to the EC.

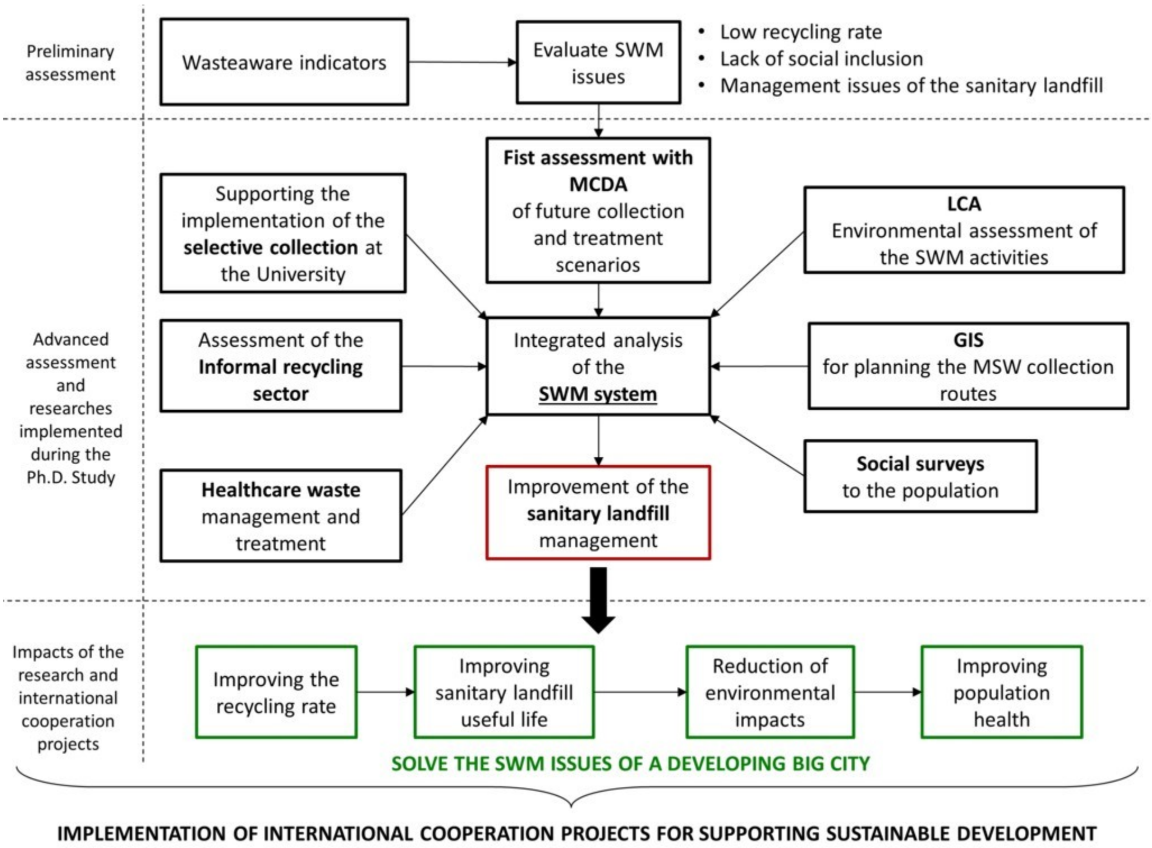


**Figure 1.3:** Overview and scheme of the research: topics and tools for improving the SWM system of La Paz.

In the last Chapter of the thesis, the draft of the two international cooperation projects is introduced. The projects are direct consequence of the research implemented. The methods used during the Ph.D., such as social surveys, LCA, the implementation of SC plans, the activities for including the informal sector, as well as the seminars and conferences, were used for improving the selective collection system of the city, also concerning the management of C&D waste. This chapter describes the third objective of the research: Draft an international cooperation project for introducing new appropriate technologies and sensitivity campaigns for boosting CE. In particular, the first project submitted to the AICS was submitted for boosting recycling, material recovery, research and information, while the second for including the informal sector and the population in the SWM system and for introducing innovative solutions and private companies.

The sections introduced within the chapters were mostly published in scientific papers or presented in international conferences. Therefore, the contents were just peer reviewed and were just published or orally presented at international conferences. All the chapters are presented by an introduction section, where the reference of the work published is presented and where the main contents are reported.

The dissertation concludes with the main impacts of the research and the future developments of the studies implemented. In particular, the methods can be used and replicated for other developing cities worldwide, and the results obtained can be an example for the implementation of international cooperation projects in low-middle income cities.

# Bibliography


[1] World Bank (2017) Bolivia. The world bank data. Available at: https://data.worldbank.org/country/bolivia

[2] Ministry of the Environment and Water (MMAyA), 2011. Solid waste management diagnosis in Bolivia. Deputy minister of potable water and sanitation, General direction of integrated solid waste management. [In Spanish]. Available online: http://www.anesapa.org/wp-content/uploads/2014/07/Diagnostico-de-la-Gestion-de-Residuos-Solidos-en-Bolivia-2011.pdf

[3] Ministry of the Environment and Water (MMAyA), 2012. National program about integrated solid waste management 2011-2015. [In Spanish]. Available online: http://www.mmaya.gob.bo/redcompostaje/files/biblioteca

[4] Swisscontact: Projects, 2017. Waste management. Available online: http://www.swisscontact.org/es/country/bolivia/proyectos/proyectos-bolivia/project//show/gestion-de-residuos-en eco-vecindarios.html, Accessed: January 2017.

[5] Wilson, D.C., Rodic, L., Modak, P., Soos, R., Carpintero, A., Velis., K., Iyer, M., Simonett, O., 2015. The global waste management outlook. Report. United Nations Environmental Programme, UNEP.

[6] Ferronato, N., Torretta, V., Ragazzi, M., and Rada, E. C. (2017). Waste mismanagement in developing countries: A case study of environmental contamination. UPB Sci. Bull, 79, 185-196.

[7] I.N.E. (2012) Características de Población y Vivienda. Censo Nacional de Población y Vivienda, Bolivia. 10.

[8] Ferronato, N., Bezzi, M., Zortea, M., Torretta, V., and Ragazzi, M. (2016). An interdisciplinary approach for introducing sustainable integrated solid waste management system in developing countries: The case of La Paz (Bolivia). Procedia Environ. Sci. Eng. Manag, 3, 71-81.

[9] Wilson, D. C., Rodic, L., Cowing, M. J., Velis, C. A., Whiteman, A. D., Scheinberg, A., ... & Oelz, B. (2015). 'Wasteaware'benchmark indicators for integrated sustainable waste management in cities. Waste Management, 35, 329-342.

# Chapter 2

# SWM in developing countries: the case of La Paz (Bolivia)

*- The benefit of generating growth and the associated pollution is mainly private while the social (environmental) cost is shared by all -*
*Sauvé S. et al. (Environmental Development, 2016)*

## Introduction

This Chapter explores the main SWM issues in developing countries and the MSWM of La Paz. It is divided in two section. In the first part, the environmental contamination due to SWM are introduced, focused on developing countries. This assessment is implemented trough a literature review of scientific papers, analyzing the management of various solid waste fractions, such as MSW, healthcare waste (HW), C&D waste, used tires and used batteries. The aim of the section is to present the main environmental issues typical of developing countries due to solid waste mismanagement. The narrative literature review described in section 2.1 was published in 2019 in the "*International Journal of Environmental Research and Public Health*" [1].

The second section contains the description of the MSWM of La Paz in 2016, with the improvements implemented in 2017 and 2018. The WBI and the WFA were used for presenting the main issues and opportunities for improving the SWM of La Paz. A discussion about the SWM issues and the comparison with other developing countries is reported. The objective of the section is to present the MSWM system of La Paz, the improvements implemented during the years and the pros and cons of the system compared with other developing countries, highlighting the difficulties occurred in January 2019, when the sanitary landfill of the city collapsed. The MSWM system studied in 2016, presented in section 2.2, was published in 2018 in the "*Waste Management & Research*" journal [2].

## 2.1 A brief review of current waste management issues in developing countries

The review presented in this section refers to the article *"Waste mismanagement in developing countries: a review of global issues" - International journal of environmental research and public health* (Ferronato, N. and Torretta, V. - 2019).

### 2.1.1 Environmental contamination due to solid waste mismanagement

Solid waste mismanagement is a global issue in terms of environmental contamination, social inclusion, and economic sustainability. Open dumping and open burning are the main practices implemented for waste treatment and disposal, with many environmental and heath impacts. Such unsustainable practices involve every waste fraction, such as MSW, HW, C&D waste, used tires, WEEE and used batteries, each one spreading specific contaminant concentrations in soil, water and air environments. Moreover, these open dump areas are vectors of disease and source of material inflow into water bodies, which improve the contamination of the seas and oceans, improving the amount of marine litter. Another global impact improved by waste mismanagement is the global warming, affected by the anaerobic degradation of organic fractions disposed of in uncontrolled sites. Finally, waste pickers works within these sites for collecting recyclable materials that are sold in local markets. Though this informal practice allows decreasing the amounts of waste inflow into water bodies and open dumps, it is also an hazardous activity that improve the health and occupational risks. Such management issues are reviewed in the next sections, highlighting main opportunities and challenges for its solution. The theoretical framework assessed is schematically reported in Figure 2.1, in order to report the logic involved in this introduction.

**MSW open dumping**

In developing countries, the management of solid waste is worsened by unsustainable practices that improve the environmental contamination and the spread of diseases. In particular, the open dumping in uncontrolled sites, open burning of waste fractions and the mismanagement of the leachate produced in final disposal sites, are the main issues detectable [3]. The situation is worsened in slum areas with additional problems of high density population, traffic, air and water pollution. Uncontrolled disposal in open spaces near water bodies are issues widespread in these contexts, which corresponds to a public health problem [4]. Concerning open air final disposal, the main environmental impacts detectable are:

- visual impacts,
- air contamination, odors and GHG,
- vectors of diseases,
- surface water and groundwater pollution,

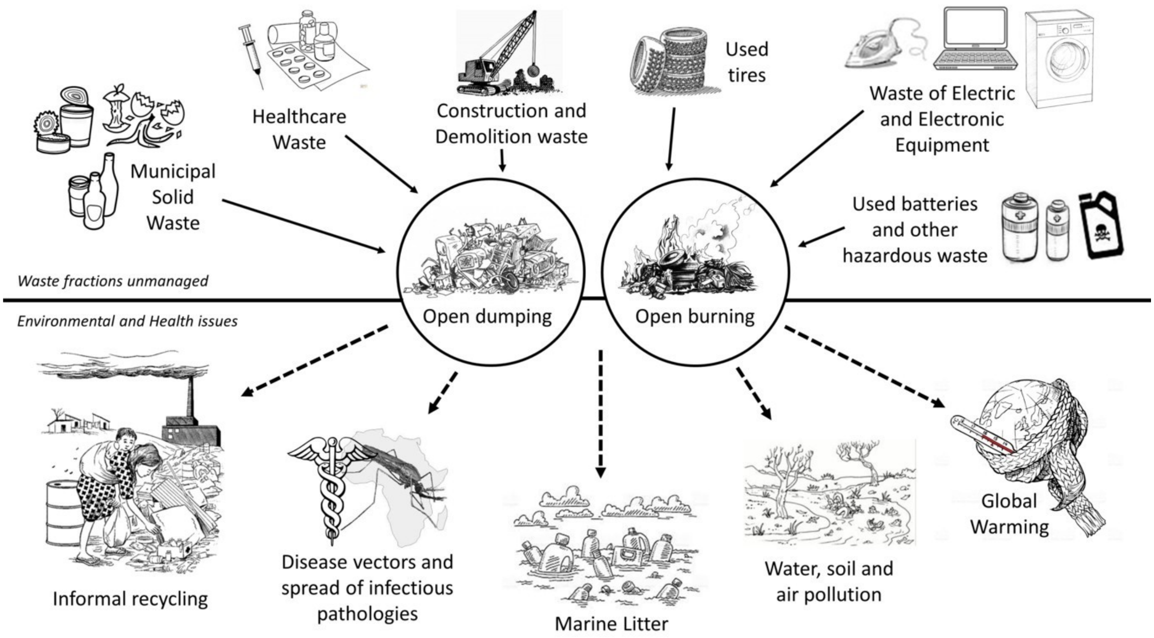


**Figure 2.1:** Theoretical framework of the source of contamination due to solid waste mismanagement, as reported in this section [1].

These issues are detectable worldwide. For example, in Banjul (Gambia) the dump site is located in a densely populated area, visible to residents [5]. It has a negative visible impact on residents and tourists visiting the country. In particular, the smoke from burning debris is the biggest issue. At times, smoke covers parts of the residential areas, affecting also the life quality of the population. Indeed, the citizens are affected by the smoke from burning debris and the smell of decomposing waste. The stench and other nuisances are worst during the rainy period as the area becomes infested with flies and insects. Run off from the dump site with contaminants dissolved inflow into water bodies, while the leachate contaminates soil and groundwater. Moreover, environmental contamination is due to the high level of fecal and total Coliform that polluted the wells located near the site. The households that live around the dump site use well water for various purposes, although with high level of coliforms attributed to the proximity to the dump site [5]. In Cambodia, in the capital city Phnom Penh, where the MSWM system lacks regulation, households commonly burned, buried, or dumped about 361,000 tons of MSW in 2008, and 635,000 million tons in 2015 [6]. In Thailand, more than 60% of the solid waste final disposal was carried out by open dumping. In 2004 there were 425 disposal sites, of which 330 open dumps, the majority of disposal sites received around 25 tons of waste per day, and only the landfills of Bangkok received about 4,500 tons per day [7]. In West Bank, Palestinian territory, in 2005 was estimated that the MSW generated was about 2728 t per day, while in 2001 there were 133 MSW dumpsites, open burned activities at 116 sites and buried at 13 sites; 64.9 % of the population was aware of the environmental issues and impacts associated with open dumpsites, and 41.6 % thought that they were suffering from the final disposal sites [8]. In Abuja, the capital city of Nigeria, more than 250,000 tons of waste were generated per year in 2010. There were four major disposal sites under its management, closed in 2005 due to odors, air pollution and burning wastes at the site. Moreover, percolation of leachate from the buried waste flowed to the surface, especially during rainy seasons [9]. In Maputo, administrative center of Mozambique, with about 1,200,000 inhabitants and where about 0.5 kg of waste per inhabitants are generate daily, the MSW is transported to the official dumpsite of the city, in operation since more than 40 years. The area is of about 17 ha, with heights that achieved 15 m; open fires and auto ignition of the waste are common issues, exacerbated by the more than 500 waste pickers collecting recyclables waste at the dumpsite [10]. Therefore, SWM issues are common worldwide, with environmental burdens and hazard for the population.

The landfill leachate generates in open dump sites contains concentration of organic carbons, ammonia, chloride, heavy metals [11], as well as high concentrations of fluoride, chloride, ammonium–nitrogen and the ratio of biological oxygen demand (BOD) and chemical oxygen demand (COD) [12]. For instance, the MSW dumped at Mathkal dumping ground, Kolkata, India, is affecting the degradation of water quality in and around dumpsite area: Cd and Ni are detectable in leachate, improving groundwater contamination in and around the landfilling area; the metals Pb, Cd, Cr and Ni are characterized as toxic one for drinking water, and the concentration of these components increases under favorable conditions close to a landfill and may lead to a serious toxic risk. Indeed, It has been reported that the concentration of Cr, Cd, and Mn were higher in the groundwater due to leachate, affecting the life of the population and the quality of the environment [13].

In Chennai city, capital of Tamil Nadu, India, where more than 3,200 t of solid waste are generated, the leaching of heavy metals in the water imposes serious health risks to humans. Heavy metal concentration of the soil samples at various depths ranges from $3.78\, mg\, kg^{-1}$, to $0.59\, mg\, kg^{-1}$ at a depth of 2.5 to 5.5 m, with concentration higher in the top soil up to a depth of 5.5 m (sandy clay layer). Therefore, the concentrations of heavy metals decreased with increasing soil depth, demonstrating the influence of the dumping activities [14]. In Nonthaburi dumpsite, Thailand, the concentration of heavy metals was detected in boreholes and runoff. Within the runoff and the groundwater, the concentrations of chrome, cadmium, lead, nickel and mercury, are always 10 times above the limits introduced by the World Health Organization (WHO) for drinking water [15]. In Tiruchirappalli district, India, the MSW generation is about 400–600 tonnes per day and is served by an open dumping yard located 12 km from the city. The leachate shows that the range of COD varies $29,880 - 45,120\, mg\, L^{-1}$ and the $BOD_5/COD$ ratio was less than 0.1. Based on the average concentration, the concentration of lead and cadmium were 5 and 11 times higher the soil contamination limits. The presence of heavy metals (Pb, Cu, Mn, and Cd) in soil sample, undetectable in the near areas, indicates that there is appreciable contamination of the soil by leachate migration [16].

In Table 2.1 are reported pollutants' concentration in soil, runoff and groundwater in eight different case study compared with the limits imposed by international organizations. In the case studies reviewed, the analysis were implemented at a distance variable from 20 to 400 from the final disposal sites. Data about runoff and groundwater contamination were compared with drinking water limits since, in low-middle income areas, groundwater is the most use for drinking without adequate treatments. Results reported always a correlation between leachate and environmental contamination. Heavy metals are always the ones persistent within the samples, also 10 times more the limits suggested by the WHO, with high concentrations of COD. So, open dumping pose surrounding population to serious health risks.

| Ref. | City/region | Country | Environment polluted | Pollutant | [c] | Limits |
|---|---|---|---|---|---|---|
| [14] | Chennai city | India | Soil ($mg\,kg^{-1}$) | Zn | 0.27 - 0.48 | 50 |
| | | | | Cu | 3.78 - 0.59 | 100 |
| | | | | Fe | | - |
| [16] | Tiruchirappalli | India | Soil ($mg\ kg^{-1}$) | Mn | 171.16 | 500 |
| | | | | Pb | **291.3 >** | 50 |
| | | | | Cd | **47.7 >** | 4 |
| [17] | Havana | Cuba | Soil ($mg\,kg^{-1}$) | Cobalt | 8.4 | 20 |
| | | | | Ni | **50 >** | 30 |
| | | | | Cu | **252 >** | 100 |
| | | | | Zn | **489 >** | 50 |
| | | | | Pb | **276 >** | 50 |
| [18] | Uyo | Nigeria | Soil ($mg\,kg^{-1}$) | Pb | 9.9 - 11.8 | 50 |
| | | | | Zn | **137 - 146 >** | 50 |
| | | | | Ni | 11.8 - 12.6 | 30 |
| | | | | Cr | **3.6 - 4.1 >** | 1 |
| | | | | Cd | **9.05 - 12.2 >** | 4 |
| | | | | Mn | 91.2 - 94 | 500 |
| [15] | Nonthaburi | Thailand | Runoff ($mg\,L^{-1}$) | Mn | 0.49 > | 0.4 |
| | | | | Cr | **0.99 >** | 0.05 |
| | | | | Cd | **0.01 >** | 0.003 |
| | | | | Pb | **0.1>** | 0.01 |
| | | | | Ni | **0.5 >** | 0.07 |
| | | | | Zn | 1.32 | 4 |
| | | | | Cu | 0.63 | 2 |
| | | | | Hg | **0.95 >** | 0.002 |
| [16] | Tiruchirappalli | India | Groundwater ($mg\,L^{-1}$) | Cd | 0.16 - 1.04 > | 0.003 |
| | | | | Cu | **0.6 - 2.7 >** | 2 |
| | | | | Mn | **0.2 - 1.8 >** | 0.4 |
| | | | | Pb | **0.8 - 5.1 >** | 0.01 |
| [19] | Mexicali | Mexico | Groundwater ($mg\,L^{-1}$) | $BOD_5$ | 4.3 - 6.5 > | 20* |
| | | | | COD | **23.5 - 188 >** | 120* |
| | | | | Na | **600 >** | 200 |
| | | | | $SO_4^-$ | **1000 >** | 300 |
| [20] | Sepang | Malaysia | Groundwater ($mg\,L^{-1}$) | $BOD_5$ | **128 - 142 >** | 20 |
| | | | | COD | **2,698 - 2,891 >** | 120 |
| | | | | Cl | **123.8 - 127.7 >** | 5 |
| | | | | Ni | **0.44 - 0.65 >** | 0.07 |
| | | | | As | **0.06 - 0.07 >** | 0.01 |
| | | | | Pb | **0.04 - 0.08 >** | 0.01 |
| [21] | Alexandria (landfill) | Egypt | Groundwater ($mg\,L^{-1}$) | Ni | **0.007 - 0.152 >** | 0.07 |
| | | | | Pb | 0.002 - 0.009 | 0.01 |
| | | | | Cr | **0.006 - 0.058 >** | 0.05 |
| | | | | Mn | **0.039 - 0.673 >** | 0.4 |
| | | | | Cd | **0.001 - 0.051 >** | 0.003 |
| | | | | Zn | 0.001 - 0.343 | 4 |

*Note: Soil contamination limit [22], Drinking water limits [23], * water release after wastewater treatment.*

**Table 2.1:** Contaminants' concentration in soil, runoff and groundwater due to open dumping in eight case study, compared with international standard of soil contamination limits and drinking water.

**Marine Litter: a global issue**

Open dumping cause surface water pollution due to leachate mismanagement and material uncontrolled flows. A visible impact that is affecting the seas and the oceans globally, is the marine littering, which is mainly caused by plastic waste. Marine litter is defined as manufactured or solid waste entering the marine environment irrespective of the source, and the the range and scale of impacts from marine litter are diverse [24]:

- Environmental (ingestion - poisoning -, blockage of filter, physical damage of reefs, mangroves...)
- Social (loss of visual amenity, loss of indigenous values, risks to health and safety)
- Economic (cost to tourism, cost to vessel operators, losses to fishery, costs for clean up, animal rescue operations, recovery and disposal)
- Public safety (navigational hazards, hazards to swimmers and divers, cuts, abrasion and stick injuries, leaching of poisonous chemicals, explosive risk)

About 80% of marine litter generation is mainly caused by the mainland, by the rivers that inflow into the seas and lakes [25]. Therefore, open dumping can be considered as the first cause of pollution of the oceans. More hazardous is the generation of micro-plastics; Once in the ocean, most plastics tend to stay at or close to the surface where they photo-chemical, mechanical and biological processes degrade larger items into smaller, including < 5 mm, forming the micro-plastics [26]. Potentially, micro-plastics with are ingested when present in the marine environment and tend to float on the sea surface. There, they can be ingested passively or actively by a wide range of organisms [27]. A simple scheme has been provided by do Sul et al. (2014), where it is clarify the definition of direct or indirect ingestion of micro-plastic, which can affect human health (Figure 2.2).

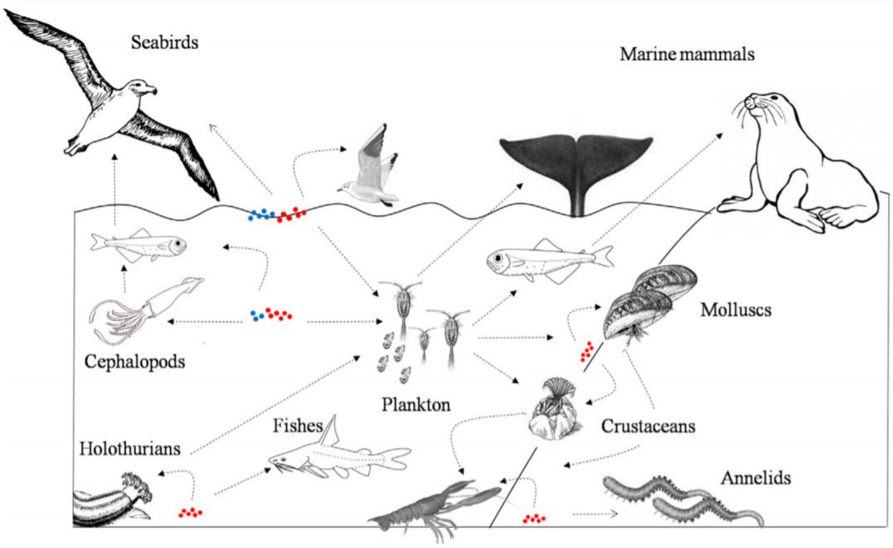


**Figure 2.2:** Schematic analysis of the trophic chain of micro-plastic in the marine environment provided by do Sul et al. (2014) for explaining plastic direct and indirect ingestion [27].

A study published in 2019 reported that, in the Mediterranean sea, micro-plastics are 94.6% in number and 55%wt. of all plastics whereas meso-plastics represented 5.3% in abundance and 45% in weight of all plastics. In thi study, only 1 macro-plastic was sampled, which represented 0.1% in abundance of all plastics and weighed five times more than all the collected plastics together [28]. It means that the amounts of micro-plastic is increasing, improving the risk of direct and indirect intake within the trophic chain, achieving human feeding. Moreover, a study conducted in the Pacific ocean, discovered plastics of the 60', which means that the marine littering and the pollution of the sea is 60 years old, improving the amount micro-plastics into the marine environment [29].

The implementation of sound waste management collection and disposal practices, involvement of manufacturers, and behavior change are key aspects of any solution. At an intermediate stage, innovation is needed around the litter generation points: upstream, redesigning goods for reducing generation quantities and mitigating the risk posed by used plastics in marine environments; and downstream, improving collection and treatment systems. Long-term technical solutions for recovering the existing used plastics in the world's seas should also be implemented [3]. Finally, a specific focus on low-middle income countries should be implemented, since is the main source of pollution although the generation rates are the lowest.

**MSW open burning**

Waste open dumping is not the only environmental burden due to waste mismanagement. The combustion of waste with any precaution generates also contaminants, improving health risks to the population. Poly-chlorinated dibenzo-p-dioxins (PCDDs), poly-chlorinated dibenzofurans (PCDFs), and poly-chlorinated biphenyls (PCBs) were detected in soils around dumping sites in the Philippines, India, Cambodia, and Vietnam [30]. Uncontrolled combustion, generation of methane gas, and low-temperature burning are major factors for the formation of dioxins in dumping sites. Considerable loading rates of PCDD/Fs in the dumping sites of these countries (200 - 4000 tons per day) were observed, ranging from $0.12 - 35 mg_{TEQ} yr^{-1}$ [30].

Open dumping sites in Surabaya and Palembang, Indonesia, have concentrations of PCDD/Fs and dioxin-like Polychlorinated byphenyls (DL-PCBs) in soil of about $61,000 - 310,000\, fg_{TEQ}\, g^{-1}$ (dry weight) and $6,300 - 32,000\, fg_{TEQ}\, g^{-1}$, respectively. Low levels of PCDD/Fs and DL-PCBs, ranging from $75$ to $98$ and $0.32$ to $95\, fg_{TEQ}\, g^{-1}$, respectively, were observed in soil for an open dumping site that included a top cover layer of soil. The difference in concentrations can be explained by the fact that open burning of waste is the source of PCDD/Fs and DL-PCBs. A sensitivity analysis implemented in this area found that the maximum emission factor could be $5,600,000\, fg_{TEQ}\, g^{-1}$ [31].

A controlled incineration that treated about 100,000 t of MSW per year, required for a city of about 350,000 inhabitants who generate about 0.8 kg MSW per day, generates about $40,000 fg_{TEQ}\, m^{-3}$ [32], which is equal to $24 mg_{TEQ}\, yr^{-1}$, considering a production of $6,000\, m^3$ of combustion gases per ton of waste burned. Therefore, open dumping can generates more quantities of dioxins per year, also with uncontrolled leachates, diseases vectors, odors and GHG, affecting the environment and population's health. Such practice should be avoided, and replaced with appropriate and sustainable technologies. Know-how is required, as well as financial support for improving waste recovery and final disposal.

**Health and environmental risk due to HW mismanagement**

Solid waste is not only municipal. There are various fractions hazardous for the environment and the population health that is generally mismanaged in developing countries. One of these fractions are the HW.

The term HW includes all the waste generated within health-care facilities. In addition, it includes the same types of waste originating from minor and scattered sources, including waste produced in the course of health care undertaken in the home. Between 75% and 90% of HW is comparable to MSW, so “non-hazardous” or “general health-care waste”. The remaining 10–25% of HW is hazardous and may pose a variety of environmental and health risks [33]. Details about HW fractions is reported in Table 2.2.

| Waste category | Descriptions and examples |
|---|---|
| Sharps waste | Used or unused sharps (i.e. needles; syringes with attached needles; knives; blades; broken glass) |
| Infectious waste | Waste suspected to contain pathogens and that poses a risk of disease transmission (e.g. waste contaminated with blood and other body fluids) |
| Pathological waste | Human tissues, organs or fluids; body parts; fetuses; unused blood products |
| Pharmaceutical waste | Pharmaceuticals that are expired or no longer needed |
| Chemical waste | Waste containing chemical substances (e.g. laboratory reagents; film developer; disinfectants that are expired or no longer needed; broken thermometers with mercury) |
| Radioactive waste | Waste containing radioactive substances (e.g. unused liquids from radiotherapy or laboratory researches) |
| Non-hazardous or general HW | Waste that does not pose any particular biological, chemical, radioactive or physical hazard |

**Table 2.2:** Categories of HW as reported by the WHO [33].

Open dump is the most common method of HW disposal in developing countries. Though, this method also is the least cost option, it is uncontrolled and inadequate disposal, since the waste can be accessible to waste pickers and animals. Uncontrolled clinical waste transmits infectious pathogenic micro-organisms to the environment either via direct contact through wounds, inhalation, or ingestion, or indirect contact through the food chain. Burning is aimed to reduce the volume of waste and its infectious effect. However, the burning is a potential source of generating toxic emissions like PCDD/F, among other air pollutants [34]

In west Bank, Palestine, a research shows that 82.2% of HW is disposed of in (unsanitary) dump sites and only 17.9% of health-care facilities dispose of their waste more than 7 times a week, the frequency recommended by the WHO. Therefore, the final disposal locations in the West Bank are unsanitary dump sites, which are randomly distributed throughout the region, with poor precautions for transporting and colleting the waste [35]. In Ibadan, Nigeria, Precautions, more than 60% of HW handlers did not discriminate between HW and MSW during collection and handling stages. Similarly, 66% dispose of HW with MSW at the final disposal site (open dump). Incidences of contacting diseases are prevalent among waste handlers, compared to incidence of other hospital staff. Hospital records confirmed that incidences of viral blood infections, such as Human Immunodeficiency Virus (HIV) and Hepatitis B and C, are increasing in Ibadan city. Within the open dump sites, technical and hygienic considerations are neglected or absent. For instance, several waste pickers were observed collecting HW for reselling materials consider recyclable, mostly probably to pass-on to unsuspecting poor-class patients. Moreover, leachate from waste disposal sites could be infiltrating and contaminating groundwater resources [36] In Dhaka, Bangladesh, HW is collected by waste pickers who sort the waste through the bin searching for recyclables and reusable items (syringes, blades, knives, glass, cotton, saline bags, plastic materials and metals). Scavenging activities were again observed sorting through the open dumping disposal site, increasing the risk of diseases (Figure 2.4). The research reported that both scavengers and recycling operators, revealed that neither group had any knowledge of the risks from medical waste exposure. Employers of recycling operators did not consider occupational health and safety training for their employees. The situation was still more worrying among the marginal groups of the society [37].

**Figure 2.3:** Informal HW scavenging reported by Patwary et al. (2011) in Dhaka, Bangladesh [37].

The lack of appropriate or improper HW disposal facilities in Dhaka is largely due to inadequate resources and legislation. This leads to the persistence of inappropriate practices such as the discharge of chemical waste into the general sewerage system or dumping into or near agricultural land. Hazardous waste was found to have been dumped in city corporation bins, and finally disposed of on general landfill sites, which may contaminate ground water, especially low-lying areas subject to frequent flooding. It was observed that, during the rainy season, leachate from dumps used for HW infiltrated into water that was being used for washing and household purposes as well as for agriculture [38].

Therefore, in low-income countries, HW management is an environmental and social issue that spread the risk of disease and pollution. Disposal strategies involve sorting HW at the point-of-disposal within healthcare facilities, and then transporting the infectious HW to a safe disposal site, where it is treated by incineration or other technologies and the residual product landfilled. Every treatment technologies have drawbacks, with incineration creating atmospheric emissions, and other treatments not able to handle all types of waste nor producing a treated product that is universally accepted at landfills. The best way to control the impact of HW is to train healthcare workers along with the implementation of standardized medical waste streams and disposal bin colors, which can ensure a selective collection of the waste, improving the efficiency of treatment and final disposal [39].

**Open dumping and burning of WEEE and used batteries**

Global WEEE generation has reached approximately 41 million tonnes in 2014 and increasing at a rate of 3–5% every year. The production of WEEE was correlated with the GDP, while there is no significant correlation or trend with the population. If this waste is properly recycled, it could offer an opportunity for the recovery of copper, gold, silver, palladium and others metals with an estimated value of USD 48 billion. The conce-tration of metals in the WEEE is significantly higher than in the natural ores that these metals are mined from (for Au is almost 130 times higher) [40]. WEEE are classified in six different type of waste [41]:

- Temperature exchange equipment: refrigerators, freezers, air-conditioner, heat pump;
- Screens & monitors: televisions, monitors, laptops, notebooks,tablets;
- Lamps: fluorescent lamps, LED lamps, high-intensity discharge lamps;
- Large equipment: washing machines, clothes dryers, electric stoves, large printing machines, copying machines, photovoltaic panels;
- Small equipment: vacuum cleaners, toasters, microwaves, ventilation equipment, scales, calculators, radio, electric shavers,kettles, camera, toys, electronic tools, medical devices, small monitoring and control equipment;
- Small telecommunication equipment: mobile phones, GPS, pocket calculators, routers, personal computers, printers, telephones.

Developing countries are producing WEEE double of developed countries. It is also estimated that the developing and developed countries will discard 400–700 million and 200–300 million obsolete computers by 2030, respectively. Moreover developed countries are also exporting their WEEE to developing countries for dumping causing serious concerns. Much of the WEEE is being sent to Africa or Asia [42]; in Figure are reported the estimated flows of the waste from high income to low income countries.


**Figure 2.4:** Estimation of the legal and illegal WEEE flow from high-income to low-income countries at global level [43].

Environmentally sound management requires the establishment of collection centers, transportation, treatment, storage, recovery and disposal of WEEE. Regulatory authorities should have to provide these facilities and for the better performance there should be incentives. WEEE is becoming a source of income for the industries and opens the doors for the new jobs also. In India, Bangalore city is generating 18,000 metric tonnes of WEEE per year, and thousands of tonnes landed illegally per year. Indeed, in low-middle income countries, treatment and final disposal of WEEE is a big environmental and social concern [42].

In Lagos State, Nigeria, near an open dump site where WEEE and used batteries are disposed of with MSW, the heavy metal concentrations in well water and soil in the dry season were investigated [44]. Results reported that concentrations in wells were Pb $2.77\,mg\,L^{-1}$, Cd $0.035\,mg\,L^{-1}$, Zn $0.948\,mg\,L^{-1}$, Cr $0.520\,mg\,L^{-1}$ and Ni $1.45\,mg\,L^{-1}$, while Ni concentrations in soils ranged from $35.45\,mg\,kg^{-1}$ at a depth of 15-30 cm in the wet season to $85.43\,mg\,kg^{-1}$ at a depth of 0-15 cm in the dry season. The elevated level of metals in the well water are correlated with the metal input from leachates resulting from e-wastes that leached from the dumpsite. In fact, significant levels of Pb and Ni were found in well and tap water at the residences and dumpsite, and the concentrations of heavy metals decreased when the sampling distances from the dumpsite increased [44]. Moreover, concentrations of lead, chrome and nickel are generally higher than the ones reviewed in studies conducted near MSW open dumps (Table 2.1), suggesting that the presence of high amounts of WEEE is cause of heavy metal pollution of water bodies and soils.

In Tijuana, Mexico, a research analyzed the concentration of Cd, Cr, Cu, Pb and Ni in the soil near a open dump site where end-of-life vehicle (ELV) and WEEE are disposed of, together with the activity of waste pickers who recover the precious metals here available [45]. The mean concentrations found were $1.4\,mg\,kg^{-1}$ for Cd, $4.7\,mg\,kg^{-1}$ for Cr, $304\,mg\,kg^{-1}$ for Cu, $74\,mg\,kg^{-1}$ for Pb and $6\,mg\,kg^{-1}$ for Ni. The results of the geo-accumulation index values show that the site was very polluted with Cu and Pb. The correlation analysis shows a high correlation between Pb and Cu, which would be explained if the main source of the polluting heavy metals was the result of electrical wire burning to recover copper. The other two components detected within the research were by Cr and Ni, related to the corrosion of junk metal objects and automobile use [45]. Also in this case study, it is evident that the presence of WEEE is responsible of heavy metal pollution of the soil and therefore of the groundwater used for house uses. Therefore, within Table 2.1 were reported results of open dumps that also contains WEEE, used batteries and ELV.

Therefore, together with WEEE mismanagement, used batteries should be also mentioned. For instance, in Iran, almost 10,000 tons of household batteries were imported, most of them have been discarded in MSW without any separation and sent to sanitary landfills [46]. In addition to environmental and human health risks associated with unsafe disposal of used batteries in MSW stream, their landfilling implies the wastage of valuable resources may be important from both sustainable development and economical viewpoints. It is expected that more than 9000 tons of used batteries have been dumped in municipal landfills of Iran in recent decade. The most concern regarding battery disposal in MSW is directed to the high percentage of mercury, cadmium, lithium, nickel, arsenic and other toxic and heavy metals [46].

The challenges facing the developing countries in WEEE and used batteries management include the absence of infrastructure for appropriate waste management, lack of legislation dealing specifically withthese waste fractions, the absence of any framework for end-of-life product take-back or implementation of extended producer responsibility (EPR) [47]. Moreover, the growing rate of WEEE amount in developing countries is destined to increase in the next future, even more than expectations. A great amount (almost 50%) of current WEEE yearly generated by developed countries continues to be illegally transferred in developing countries, volumes that remains unknown; New electric and electronic products will substitute soon the current ones, influencing both collected volumes, type of recovered materials and recycling processes in an unpredictable way; Innovative materials composing WEEE (e.g. high-tech plastics and compounds or rare earths), that are currently not correctly managed during their end-of-life (ending into landfills); some electronic parts in WEEE (e.g. PCBs and HDDs) are not again correctly disassembled or recovered, leaving too early the recycling process or entering into different (and wrong) ones. [48].

In summary, many challenging issues of WEEE and used batteries management can be detected in developing countries [84]:

- Quantity of WEEE generated is a major concern due to the lack of infrastructure;
- Inventory assessment of WEEE does not exist;
- Exportation of WEEE from developed countries to developing countries for recycling worsens its management;
- Absence of knowledge regarding the toxic nature of WEEE and used batteries;
- Portion or components of WEEE are often mixed with MSW and disposed of in open dump sites;
- Deficient knowledge of the impacts to human health and the environment;
- Legislation to regulate and control the import and disposal of the generated WEEE do not exist.

**C&D waste open dumping**

The term “C&D waste” is generally used to refer to the solid waste generated in the construction sector. More specifically, the term is defined as the waste generated from construction, demolition, excavation, site clearance, roadwork, and building renovation. The main issue due to C&D waste is final disposal site landslide, which can affect the life of the population. This can be made by reducing the volume of waste dumped in landfills and to impose safe operating practices. In particular, 4Rs (reduce, reuse, recycle and recover) policies should be implemented. In particular, hazardous or toxic material should be the primary target for waste reduction [50]. As example, in 2015, a landslide in one of China’s most advanced cities, Shenzhen, killed 73 people and damaged 33 buildings, in the absence of heavy rainfall or earthquakes (Figure 2.5). According to China’s Ministry of Land and Resources, the landslide was triggered by the collapse of an enormous pile of C&D waste [51].

In Thailand, in 2014 the average generation of C&D waste was approximately 4,200,596 tons, which were disposed of in open dump sites. Hazardous and potentially hazardous materials were found, such as:

- asbestos-based materials,
- lead-based materials,

- other materials used for construction (i.e. damp-proofing chemicals, adhesives),
- mercury-containing electrical equipment (i.e. fluorescence lamps, thermostats),
- chlorine fluoride carbides (e.g. air conditioners and refrigerators),
- corrosive, flammable and toxic materials.

Hazardous waste were not separated from non-hazardous waste for proper treatment and disposal. In means that an increasing of the construction sector also contributed to the increasing of environmental pollution [52]. It has been estimated that between 2002 and 2005, an average of 1.1 million tons of construction waste was generated per year in Thailand [53]. This constitutes about 7.7% of the total amount of waste disposed in both landfills and open dumpsites annually during the same period. It means that the generation of C&D waste was affected by a relevant increase. Indeed, recently, the management of C&D waste took attention due to its rapidly increasing and unregulated dumping. Waste generation at a construction site may result from lack of attention being paid to the size of the products used, lack of interest of contractors, and lack of knowledge about construction during design activities, and poor materials handling. Generally, 50–80% of C&D waste is reusable or recyclable, so C&D mismanagement represents a loss of valuable economic resources [53].

**Figure 2.5:** C&D waste landfill landslide in Shenzhen, China [51].

In Hanoi, Vietnam, processing quantities of informal and formal C&D waste recyclers were revealed. However, current practices lacked appropriate C&D waste classifications and control of waste flows by private companies due to little efficiency or cost saving strategies, low attention for adding value to concrete waste recycling and lack of government legislative and financial support for industry transformation. Illegal dumping occurs in the city boundary, also due to the lack of technology, capacity and resources. Many construction sites mix C&D waste such as cement, bricks, steel, and plastics, disallowing the classification and recycling of these fractions. C&D recovery requires education and communication of how to separate waste, as well as a change in stakeholder perception of the value of the materials [54]. In Malaysia, in the first quarter of 2015, the construction industry in contributed 15.1% of the country’s GDP and provided employments to about 10% (1.4 million) of the total workforce in Malaysia.

Four key issues should be addressed to develop an effective C&D waste management: the increasing amount of waste, environmental impacts, illegal dumping issue, and lack of national support. The CE framework for improving C&D waste management is built following a three-layer approach; At the micro-level, the main aspects that need to be highlighted are the transformation of traditional method of construction, reducing wastes at the source; at meso-level, ensure that there is a continuous effort in managing wastes, transforming the procurement methods; Finally, at the macro-level, providing monitoring, and coordinating mechanisms to ensure the practice of effective C&D waste management [55].

Therefore, for developing countries with limited financial resources and C&D waste management initiatives and sustainable construction can be achieved through effective utilization of resources, material recovery, and an improved system for waste management. However, the first objective to be achieved is the implementation of strong regulatory initiatives for construction waste management [56]. These practices can reduce the issue of the open dumping, which is worsened by the mix with MSW and informal recycling that operates in these uncontrolled areas.

**Diseases exposure due to used tires and industrial waste open dumping and burning**

Tires that are used, rejected or unwanted are classified as ‘waste tires’, as well as tires intended to be used for retreading or recycling. This type of waste is composed of steel, rubber and textiles, and the volume depend on the used of the tires. Three main issues should be addressed concerning waste tires:

- big volumes, which reduce the useful life of the sanitary landfill and improve the transportation costs;
- open air burning of these materials, which contaminate the environment improving population health risks;
- Presence of disease vectors, such as insects or rodents, which live inside the holes and furrows of the tires.

One of the most hazardous problems regards the spread of Dengue, which is currently one of the most important diseases in tropical areas. About 2.5 billion people living in areas of risk and many millions of cases occurring each year [57]. A research assessed the breeding mosquito larvae and identifying the dengue vectors distributed throughout in, Tamilnadu, India. Totally 118 water containers were inspected, among which 38 containers were recorded as positive for dengue vector. Among all type of containers analyzed, cement cistern, mud pot and used tire were positive for the mosquito larvae [57]. Therefore, the final disposal in open dump sites of waste tires should should be avoided for reducing the spread of Dengue diseases in topical areas.

Another impact that affect the population health is the uncontrolled burning of waste tires. In Nepal, where the uncontrolled open-air burning of waste tires is practiced also during political agitation, a research was conducted to provide background information for assessing the environmental pollution due to the tire fires [58]. The effect of the tire fires on air is a major concern, because they release potentially hazardous gases such as $CO$, $SO_2$ and $NO_2$ as well as polyaromatic hydrocarbon (PAH) and volatile organic compounds (VOC). CO is formed whenever carbon or substances containing carbon are burned with an insufficient air supply. Tire fires, apart from intense heat, give off black carbon (BC) with CO emission. Results of the research reported that the emission levels of CO from different type of tires were $21 - 49\, g\, kg^{-1}$, $SO_2$ emission was found to be $102 - 820\, g\, kg^{-1}$, while $NO_2$ emission was $3 - 9\, g\, kg^{-1}$ [58]. These emissions can be compared with wood combustion, in order to have an indication about the pollutants of major concerns due to tires burning. Emissions of pollutants from residential wood combustion sources in wood-burning stoves are $NO_x - NO_2\, 0.5\, g\, kg^{-1}$, $SO_x - SO_2\, 0.2\, g\, kg^{-1}$, $CO\, 83 - 370\, g\, kg^{-1}$ and $PM\, 0.6 - 8.1\, g\, kg^{-1}$ while in fireplaces are of $NO_x - NO_2 1.8\, g\, kg^{-1}$, $SO_x - SO_2$ absent and $CO 11 - 40\, g\, kg^{-1}$ [59]. Therefore, it is evident that the generation of sulfur compounds most hazardous in terms of quantity generated.

Open fire issues are also detectable in high-income countries, where waste tires landfills are still an issue. A large and uncontrolled fire of a tire landfill started in Toledo, Spain, and experimental analysis were implemented for measuring the potential impact at local and regional levels [60]. Outdoor and indoor measurements of different parameters were carried out at a near school, approximately 700m down wind the burning tires. Among metals, ZnO and Co were 21 and 92 times higher than a area far from the open fire, reaching $933\, \mu g\, m^{-2}$, compared with $13\, \mu g\, m^{-2}$ in the farther zone. Increases of $SO_2$ and $PM_{10}$ levels were also detected, with sulfate hazardous concentrations ($1,371\, \mu g\, m^{-2}$), 11 times higher than the control zone [60].

A similar study was conducted in the Iowa city landfill, United States, the outdoor concentrations of pollutants generated from the 18 day tire fire were assessed [61]. The research estimated maximum concentrations of tire fire $PM_{2.5}$ smoke at distances of 1, 5 and 10 km of $243$, $55$ and $26\, mg\, m^{-3}$, respectively. $SO_2$, $PM_2.5$, BC, and air toxic VOC had also high concentrations if compared with areas far from the fire. In other studies with tire smoke, BC, biphenyl, benzene, benzaldehyde, PM, and CO were highly ranked hazards [61].

These environmental issues due tire open dumping and open burning should be addressed in an integrated manner, in order to avoid these practices. One suggestion provided by various authors is to introduce the EPR, to ensure environmentally effective management of end-of-life waste, following 4Rs [62]. This regulation tool wants to prevent waste formation and promote source reduction. If this is not possible, waste should be reused, recycled, and then recovered for energy, while landfilling should be avoided as best as possible. Accordingly, the tire EPR system should reduce the generation of tire waste, facilitate its reuse, promote recycling and other forms of material recovery and, finally, incentive the energy recovery, although LCA studies confirmed that the material recycling of tire waste provides greater environmental benefits than energy recovery [62].

Finally, other flow of environmental contamination due to waste mismanagement should be considered. Is the case of industrial waste, which is most of all hazardous There are many different type of waste generated, as well as source of contamination. Only as an example, in a tanneries area located in Ranipet (India), where were manufactured chromate chemicals, a large quantity of hazardous solid wastes were stacked in open dump sites. This practice resulted in fast migration of the contamination to the water table, with levels of chromium in the groundwater up to $275\, mg\, L^{-1}$, 1000 times higher than the recommendations of the WHO fro drinking water. The findings are of relevance to addressing the groundwater pollution due to indiscriminate disposal practices of hazardous waste [63].

### 2.1.2 Informal sector and social inclusion

Worldwide, there is a considerable presence of the informal sector in waste management, particularly in low-middle income cities where there is no formal SC system for recyclable materials. Informal activities tend to intensify in times of economic crises and where imported raw materials are quite expensive. However, The inclusion of the informal sector in SWM remain a problematic issue and considerable attention from NGOs and scholars is arising for solving such issue [3]. In Figure 2.6 is reported a simplified scheme that represent the selective collection chain of the informal sector [64]. The structure is of a specific case study in China, however, thestructure is similar in many case studies worldwide. The informal pickers collect the waste in open dump sites, bins, roads and household for segregating recyclable materials. These people can be organized or alone, with or without means and merchants or simply pickers. The waste is then sold to trading points that collect the waste and sell it again to formal or informal recyclers or directly to manufactures. This structure can be recognized worldwide.

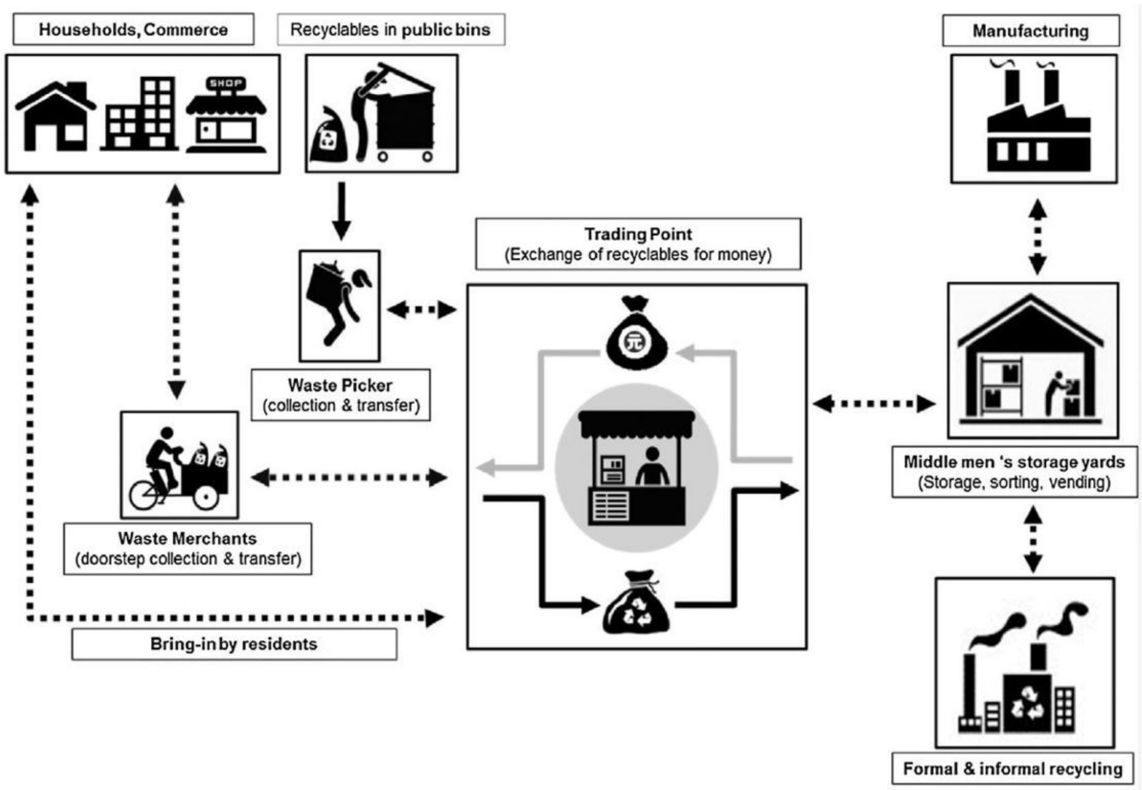


**Figure 2.6:** Informal recycling chain in China, as schematically depicted by Steuer et al. (2018) [64].

Many studies were implemented and published in the scientific literature, in order to assess how the informal sector could be included in the formal management or recognized by the local population. For instance, in Ulaanbaatar, Mongolia, the informal sector operates into the informal neighborhoods. In these areas illegal dumping is common and some open fields became uncontrolled disposal sites, with waste pickers working and living near these areas. In 2004, the World Bank estimated that about

5,000 to 7,000 informal recyclers worked in Ulaanbaatar, and today this number could be higher increase in city's population. The research conducted in the city revealed that most waste pickers have also higher education at a university, suggesting that the activity is due to many factors (i.e. lack of work). Informal waste pickers select recyclable materials and bring them by foot to secondary dealers for obtaining an income, who then sell larger quantities to the respective recycling industries. [73]. In Blantyre, Malawi, MSW is dispose of in pits, on the road-side, or on the river. Waste pickers process and transform recyclable materials reducing the amount of waste disposed at dumpsites and reducing the use of virgin materials needed for manufacturing. However, waste pickers are rarely recognized for their contribution. The two wastes categories selected by the pickers are plastic and metals. No data are available for quantifying the number of waste pickers, however it was estimated that the maximum quantity of waste selected per day was about $20 - 30\,kg\,d^{-1}$ [66]. In Harare, Zimbabwe, where the quantities of waste generated within the city are not known, the informal sector operates, mainly in open dump sites. Indeed, the waste collected by theformal collection is disposed of in dumpsites, where about 220 waste-pickers worked. Waste-pickers had to wait for a worker's signal before they could start recovering materials and a waste picker required a license to enter the dumpsite. It was estimated that waste-pickers recovered about 6–10% of waste deposited at Pomona (about 27 - 50 tons per day) Competition with others pickers was considered as the major challenge for the collectors, as well as workplace health and safety and discrimination among the population [67]. Finally in Iloilo City, Philippines, where 170 tons of waste (about 50% of the total generated) are disposed of in a open dumpsite, approximately 300 households recover recyclable material for selling it in the market. A pilot project with international NGOS was implemented, in order to convert the organic waste into energy through briquette production. Results of the study show that the integration of the informal sector in the production of biomass briquettes can be a good option for implementing integrated plans for including informal recyclers, especially in areas where their activity is forbidden, as in Philippines [68].

In Table 2.3 seven case studies are compared in order to assess which are the number of pickers, their organization, its source of waste, the quantities and the fractions collected per day and the main issues detected by the researches. Results reported that waste pickers operate both in low income (Zimbawe) and high income countries (China). Mostly, informal sector collect waste from uncontrolled open dump sites, and are not recognized or organized by the local municipalities. Waste pickers can collect from 14 to 60 kg of recyclable waste per day (WEEE, MSW and HW).

With regard to the environment and resources, the benefits are evident in many cities. In some places informal-sector service providers are responsible for a significant percentage of waste collection. In Cairo, Egypt, the informal recycling is implemented since the recyclable waste recovered are sold to the private companies, while the organic fractions are used for breeding pigs [72]; in Dhanbad Municipality, India, informal recyclers play an important role in the plastic waste management, collecting the recyclable plastic waste from landfills, rendering environmental and social benefits [74]; In Bogotá, Colombia, informal recyclers collect materials from waste, motivated by profits, due to the free-market enterprise for recycling [75].In all these international realities, the main factor that allows the activity of the informal sector is the presence of low-income communities and the free management of waste. Bolivia has the same characteristics and the informal sector acts since the price of the recyclable waste is still a good source of income.

| Ref. | City | Country | n. of w.p. | Org./ for. | Source of recyclables | $kg\,d^{-1}$ per w.p. | Waste fractions | Issues |
|---|---|---|---|---|---|---|---|---|
| [69] | Kathmandu | Nepal | 7,000-15,000 | No | City streets / landfill | 60 | Plastic bottles, plastic bags, paper, glass, iron, HW. | Illnesses, lack of financial resilience, occupational risks. |
| [66] | Balantyre | Malawi | N.A. | No | Open dumps in urban areas | 20-30 | PET, HDPE, LDPE, metals | Negative public perception, lack of capital, fluctuation of the price |
| [67] | Harare | Zimbawe | 220 | Licensed | Open dumps | 70 | Plastic, paper, rubber, metals, glass, tires | Competition with others w.p., safety issues, discrimination, climate conditions. |
| [73] | Ulaanbataar | Mongolia | 5,000-7,000 | No | Dumpsites, public areas, streets. | N.A. | Plastic, cans. | Alcohol addiction, no ID card, homeless, discrimination, diseases |
| [64] | Beijing | China | 150,000 | Prohibited by regulation | Households, public bins, small enterprises. | 14 - 16 | WEEE, paper, metals, plastics. | Minimum wage standards, discrimination |
| [70] | Great Accra Region | Ghana | N.A. | No | Landfills, open dump sites. | N.A. | Metals, Plastics, PET, WEEE | Health hazards, cuts & injuries, insects bites, lack of respect, unstable prices |
| [75] | Bogota | Colombia | 20,000 | Cooperative | Trash bags, public bins. | 25 | Plastics, metals, paper, glass. | Lack of public acceptance, health, cleanness of operation. |

*Note: (n.) number; (w.p.) waste pickers; (Org./for.) organization and formalization; (N.A.) not available .*

**Table 2.3:** Comparison of the waste pickers' activity among seven different countries worldwide.

Therefore, the activity of the informal sector contributes directly to the recovery of the materials and the reduction of environmental contamination. This practice is in accordance to the CE principles. The objective of the CE is closing of material loops, to prevent waste from final disposal, and transforming the resulting residual streams into new secondary resources [78]. It proposes a system where 3Rs provide alternatives to the use of raw virgin materials, making sustainability more likely [77]. The CE typically includes economic processes such as "reverse logistics" or "take back" programs that recover wastes for beneficial reuse, avoiding final disposal costs, often reducing raw material costs and even generating incomes [79]. Therefore, the inclusion of the informal sector and the improvement of SCS represent a key strategy for improving the CE concepts, improving social, environmental and economic sustainability [80].

The activities if the informal sector regards the degree of formalization, from unorganized individuals in dumpsites, to well organized cooperatives. Issues such as exploitation by middlemen, child labor and high occupational health risks need to be challenged for addressing sustainability. Globally, SWM remains a negative economy, where individual citizens pay the cost, the financial viability of recycling is disputed, and the sector remains vulnerable to great price volatility. Most of the collection systems in place in developed countries are subsidized to variable degrees, and also result in substantial exports of recyclables in global secondary resources supply chains. Moreover, if taxes, health insurance, child schooling and training provisions, management costs and other typical costs are included within the informal waste sector, can be that the sector come back to being unsustainable economically [81].

It is recognized that a door-to-door collection service of source-separated recyclables may be one of the best solutions for improving RR. Therefore, the informal sector have the opportunity to deliver important environmental benefits, becoming an active agents of behavior change. Moreover, its activity can reduce the waste inflow into water bodies, decreasing the amount of marine litter in the oceans. So, the inclusion of the informal recycling should be more investigated, assessing pros and cons of its activity in different realities worldwide [81].

### 2.1.3 Challenges and opportunities

From the review it is clear that there is a strong linkage between poor SWM and environmental/health issues. The rapid increase in population, economic growth, urbanization and industrialization improve the generation of solid waste at global level, boosting environmental contamination when such solid waste is not managed. Indeed, in many developing countries waste are scattered in urban centers or disposed off in open dump sites. The lack of infrastructure for collection, transportation, treatment and final disposal, management planning, financial resources, know-how and public attitude reduces the changes of improvement, as pointed out also by other authors [82].

Nevertheless, the generation of solid waste can be also considered as source of opportunities: generation of renewable energy, new employment, new economic advantages, private investments and improvement of population awareness about environmental issues. In developing countries, the informal sector plays the main role in recycling where plastic, glass, metal and paper have a developed market. Appropriate strategies should be introduced for supporting these activities, such as improve public awareness, enact specific laws and regulations and implement SWM infrastructures. Support can be provided with the assistance of NGOs, private companies or international funds, for boosting the 3Rs, which included waste separation at the source, involving residents, institutions, local governments and local companies. Therefore, some recommendations should be introduced for improving the SWM systems at global level, as also suggested by other studies [83].

- Improve public education and awareness among citizens and waste pickers,
- Improve financial sustainability of the SWM systems,
- Involve several stakeholders for improving system resilience,
- Include safety precautions in the informal recycling sector,

- Implement researches for assessing waste composition and characteristics.

In developing countries, in agreement with the results of a LCA research, good environmental protection can be accomplished by recycling and composting, since high fractions of OFMSW are associated with environmental impacts [84]. Such options are in agreement with the principle of the CE, emerging topic that has attracted research interest. However, three components should be included in definition of CE [85]:

- re-circulation of resources and energy, recovering value from waste,
- implementation of multi-level approach,
- the way society innovates during the years.

These principles are mainly implemented in European countries and in China, while in low income countries these activities still lack of development [86]. Furthermore, another research found that the main incentive for the development of SWM in municipalities was the economy; Environment and public health are only secondary drivers [87].

Therefore, CE patterns specific for developing countries should be introduced, focusing on big cities, since financial sustainability, multi-levels approaches and energy recovery are options that to date are not affordable in these contexts.

The next section introduces the MSWM system of La Paz, assessing the main opportunities and challenges involved in its implementation. The objective is to analyze which barriers should be overcome for introducing a CE model into the city, focused on social inclusion, environmental protection and economic sustainability.

## 2.2 MSW management in La Paz: "Wasteaware" benchamark indicators and waste flow analysis

The research presented in this section refers to the article *”The municipal solid waste management of La Paz (Bolivia): Challenges and opportunities for a sustainable development”* - *Waste Management & Research* (Ferronato, N., Gorritty Portillo, M. A., Guisbert Lizarazu, E. G., Torretta, V., Bezzi, M., and Ragazzi, M. - 2018)

### 2.2.1 Methods

The research was implemented by the used of the WBI and the WFA, which were used for assessing the MSWM issues of La Paz and planning future plans [88]. The first field work took place in 2016, while other assessments were introduced in 2017 and 2018. Data were collected from primary sources, such as data from the local authorities, engineers and experts in the field of MSWM, and secondary sources, which were mainly gathered from documents and previous studies.

**Primary sources** allow implementing qualitative and quantitative analysis:

- the qualitative investigation has been useful for understanding MSWM local dynamics in order to obtain information about the quality of the service
- the quantitative approach was used to build the waste flow. In particular, in this section is presented the WFA introduced in 2016 and the one detected in 2018, although the quality of data suffers of uncertainty.

Both were carried out by interviews, observations and field surveys. The interviews were conducted with key stakeholders in various sectors of the MSWM system such as local engineers, lawyers expert in environmental topics, economists, all working in the municipality, NGOs, Universities, private companies and the Ministry of the Environment. The observations and visits to the sanitary landfill, the recycling and sorting facilities, informal recycling shops and areas of the city, provided the information about the quality of the MSW collection, the main issues, challenges and strengths of the MSWM system.

All the interviews allowed obtaining data about waste streams into the landfill, the quality of the service provided, informal recycling activities applied in the city, exploitable waste prices in the informal recycling shops, actors involved, quantities of waste exploited in the recycling business and knowledge in waste management legislation. Financial flows were not included in this analysis due to limited available data.

**Secondary data** were collected through the analysis of local documents provided by the GAMLP, the NGO Swisscontact, and available online [89]. These sources provided baseline information about the MSWM practices introduced into the city. These collected data are quantitative, since they are related to the waste composition, waste quantities produced, number of waste pickers, informal recycling shops and citizens.

#### WBI and WFA

A literature review about waste management indicators applied in other contexts worldwide, such as Bahrain [90], Bishkek in Kyrgyzstan [91] and Lahore in Pakistan [92] was conducted and the WBI [88] applied for Monrovia, Maputo, Lahore, Guadalajara and Belfast, has been considered the representative one to comprehend La Paz local state and to compare it with other developing big cities. Moreover, other studies that implemented the WBI were reviewed for comparing the case of La Paz with other worldwide, such as Accra (Ghana) [93], Ulaanbaatar (Mongolia) [94], Chandigarh (India) [95] and Bangkok (Thailand) [96].

The WBI allowed assessing, commenting and compactly presenting all relevant topics that should be considered in a MSWM plan. For that reason, the WBI were suggested to the La Paz municipality and were used to evaluate the MSWM system in this study.

It is important to underline that the work has been carried out only for MSW and primary data are related to the year 2016, 2017 and 2018 while secondary data are derived from past documents which were confirmed by local experts. This means that industrial scale C&D waste, healthcare waste, hazardous waste and industrial waste are not considered in the WBI and are not assessed in this section.

The indicators introduced within the WBI are expressed in percentages, and are divided in quantitative indicators and qualitative ones. In particular, the WBI is composed of twelve indicators, divided into a physical component and a governance one [88].

- The physical components are divided into four quantitative indicators and three qualitative indicators. The quantitative indicators measure waste collection coverage, waste captured by the solid waste management and recycling system, controlled treatment or disposal and recycling rate. Such indicators are indicated by the numbers 1.1, 1.2, 2 and 3 respectively. Whereas, the qualitative indicators are divided into six criteria, expressed in a five-fold scoring system with a score of 0, 5, 10, 15 or 20, and assess quality of MSW collection and street cleaning service (1C), degree of environmental protection in waste treatment and disposal (2E) and quality of the 3Rs.

- The governance component of the WBI is divided into five other indicators, built by six criteria (questions used to derive the quantitative percentage for the qualitative indicator), which provided indications about the degree of user inclusivity (4U), degree of provider inclusivity (4P), financial sustainability (5F), adequacy of national SWM framework (6N) and, finally, local institutional coherence (6L).

The WFA has been applied as a useful tool for understanding main flows of the material within the specific area [97, 98]. Moreover, this tool is also required for the application of the WBI. It was implemented in order to identify the main MSW streams and describe the management activities during the year 2016 and 2018, as a comparison. Data sets are extracted both from primary and secondary sources, with the estimated quantities assessed by expert judgment. Reliable data are only available at the final disposal site, while there are no data related to the other MSW sources, such as street sweeping, business activities and households. As a result, there is no specification about the source of the MSW, while the streams related to the formal and informal recycling system are provided. For implementing the WFA, the software STAN 2.5© (Institute for Water Quality Resources and Waste Management –TU-Wien, Austria, 2016) has been used. The functional unit of the waste flow diagram is ton per day.

### 2.2.2 Results - Physical components

#### Waste collection

The waste collection service in La Paz is evaluated by two quantitative indicators: waste collection coverage (1.1) and waste captured by the solid waste management and recycling systems (1.2), and one qualitative indicator: quality of the waste collection and street cleaning service (1C) of the WBI.

Until October 2016, two private companies managed the MSW collection and treatment: TERSA and SABEMPE, whereas, after this period, another private company, “La Paz Limpia”, took the place of SABEMPE since it ended the business agreement with the Municipality, and the methodology for collecting the MSW changed by the introduction of new street containers.

TERSA was responsible for the final disposal and the collection from few districts within the city, which covered 15% of the city extent; SABEMPE had the task to collect the waste from the remaining 85% of the city and operated the city center street sweeping, that was mainly a manual activity. Both companies were responsible for the provision and maintenance of the infrastructures for the MSWM system, like street containers and transportation trucks in their areas of competence. Moreover, the MSWM service is supervised by the municipal entity SIREMU, which works directly for the local Government with the aim to monitor the operations of the private sector. Regulation and surveillance of MSW are responsibilities of the secretary of the environmental services of the GAMLP which also plans the future service provision.

The MSW is collected in two main approaches: fixed point collection and curbside collection. Then MSW streams are transferred directly to the final disposal site.

- In the fixed-point collection method, MSW is stored for days along the road, since users do not respect the waste service time table.

- Curbside collection methods consist of waste collection trucks which provide long hooting signals (using a whistle) inviting residents to bring out the waste, which is loaded directly into the trucks.

The collection is guaranteed, on average, two times per week, depending on the area. It is common that the collection service is applied more than three times per week in the city center, while in suburban areas is not applied at all. These information were gathered also by a questionnaire survey implemented at the University in 2016 [99]. The fixed-point collection is not adequate for guaranteeing the street cleaning and public hygiene due to foul smell and proliferation of flies and other vectors. Moreover, the collection points (where there are) suffers bad maintenance and the collection trucks are not always compactors.

Moreover, a form of waste segregation at the source is applied: The Municipality, supported by the Swiss NGO Swisscontact from 2014 to 2016, introduced a sensitivity campaign for improving citizens’ recycling behavior. Such activities are applied at “Green-points” (GP), free areas implemented for separate collection of recyclable waste materials delivered voluntarily by the citizens. These activities are applied during the Saturday in the most central areas of the city, ea depicted in Figure 2.7. During the collection, children, students, users and families are informed and sensitized about new activities related to MSWM systems introduced by the municipality. However, the amounts of waste segregated in this way are only about $3\ t\ d^{-1}$, although in 2018 this amounts decreases to about $1\ t\ d^{-1}$ due to the end of the project of the Swiss NGO.


**Figure 2.7:** GP for the SC of recyclable materials implemented in La Paz (*source: personal photos took during the field work from 2016 to 2018*)

The transport of the MSW collected is carried out by 28 compactor trucks and 42 open trucks with between $10 - 12\ m^3$ loading volume. The crew size is typically composed of three members and a driver [89]. However, being a big developing city, waste collection is difficult due to narrow streets and the absence of urban planning.

Moreover, collected waste represents a fraction of the total waste generated (about 87%), since only about 89% of the city is covered by the collection service [89], while other MSW streams are collected by the waste pickers and informal recycling shops. The city sweeping is done regularly, especially in central and business areas of the city, whereas it is mostly never applied in the adjacent districts.

Into the unplanned settlements, which are far from the city center, the indiscriminate MSW disposal applied by the citizens along roads, water bodies and green areas, is very common. Moreover, the open burning is practiced by several citizens in these areas, where the public waste collection cannot provide an efficient and continuous service due to the lack of infrastructure, as usual in low-middle income countries [100, 101, 102]. These amounts of waste are not known, although can be estimated, as indicative data, to form 5% of the total MSW produced in La Paz. Hence, the uncaptured waste, produced the remaining 11% of the city uncovered by the system, is burned, dumped to the rivers or scattered in little open dump sites around the city, in 2018 as in 2016.

**Final disposal**

The final disposal of the MSW is assessed by the quantitative indicator: Controlled treatment or disposal (2), and the qualitative indicator: Degree of environmental protection in waste treatment and disposal (2E), of the WBI. These criteria evaluate the final disposal of MSW in controlled site and the degree of environmental protection and monitoring.

Unlike the La Paz case study, Bolivia's towns and cities apply the practice of open dumping. These statement is confirmed by various field inspections implemented in rural areas and towns. These open dumps are sited and operated with absolutely no environmental precautions, supervision or management documentation.

La Paz can be considered as the first stage for implementing a sustainable MSW final disposal facility into the Bolivian country since the waste collected is finally disposed of to the Alpacoma landfill, 15 km far from the city center. Alpacoma final disposal site is a controlled landfill built in 2004, where all waste types (municipal, industrial, hazardous and hospital waste) are disposed. The incoming waste is weighed and then unloaded, spread and leveled by a bulldozer, except for the hospital waste, which is placed in a special cell and covered with soil and lime as a precaution measure for health protection.

The waste which arrives at the landfill, coming only from the municipality of La Paz, is mostly unsegregated and mixed with organic matter. The site is 24h controlled and enclosed in order not to allow the entrance of waste pickers, therefore no informal material separation is permitted within the site. At the end of each day the waste is covered by soil and compacted again. Landfill gas caption and leachate collection and treatment are implemented although not with the best construction standard for ensuring the full protection of water bodies and the atmosphere around the site. a representation of the sanitary landfill is reported in Figure 2.8. Moreover, the lack of air and ground water monitoring for estimating the environmental pollution do not allow understanding the degree of contamination around the landfill area.

**Figure 2.8:** Alpacoma sanitary landfill of La Paz (*source: personal photos took during the field work from 2016 to 2018*)

The MSW transported to the landfill is estimated at about 550 t/d without considering industrial or hospital wastes. High amounts of organic waste are disposed into the controlled disposal site, producing a considerable amount of leachate and landfill gas [11]. As reported by a study introduced before 2010, the MSW is mainly composed of 47.3%wt. organic fraction, 15.2%wt. plastic, 12.8% paper and cardboard, 1.4% metal, 2.6% glass and 20.7% other fractions, such as fine material, textile, inert, and hazardous waste (used batteries, municipal healthcare waste, among others). These percentages were recovered by a field study within the municipality, however it has not been replicated during the years. So, these fractions cannot be considered representative, although is the only data available locally.

### Waste valorization

The formal selective collection of the waste is assessed by the qualitative indicator: quality of 3Rs (reduce, reuse and recycle) provision (3R) and the quantitative indicator: recycling rate (3), of the WBI.

La Paz MSW quantities are available only at the landfill, unlike the waste recycled along the waste informal chain, as typical in developing countries [103]. La Paz

MSWM system includes the application of a SC system, although the amounts of waste collected by this methodology are low. The recyclable materials are selected into a manual selection plant while the organic fractions are treated in a composting facility.

The composting facility, situated at an old open dump area located in the south of the city, receives $4\ t\ d^{-1}$ of organic fraction gathered from street markets, maintenance of urban green areas and the zoological park [104]. Here the organic matter is converted into compost by a vermicomposting process, viable option in developing countries [105]. The organic material, segregated at the source, is mixed with the same quantity of organic fraction where worms were bred. The resulting mixed organic fraction is gathered in outdoor static piles, 3 to 5 m high, as reported in Figure 2.9. The static piles are not aerated and are turned after 20 days. During the first 35 days the process is controlled and monitored for guaranteeing correct pH, moisture and temperature, while, after this period, the organic compound is stored statically for six months for achieving the final maturity and stabilization of the compound.

**Figure 2.9:** Vermicomposing process for treating ogranic waste produced in the public markets of La Paz (*source: personal photos took during the field work in 2018*)

This methodology is used for producing compost which is exploited to reclaim the old open dump where the composting plant was located and create a new green area [104, 106]. In particular, the final compost is used as new soil for planting new trees. It is not a large plant; however, it can be considered a start point for improving La Paz organic waste recycling system since, currently, the main activity applied for the organic and food waste is the final disposal to landfill.

Concerning the manual sorting plant, in 2016 the site received, on average, a total of $3\ t\ d^{-1}$ of recyclables materials to be manually sorted there, such as plastic, paper and glass (Figure 2.10. This waste comes from the GP of the city. The capacity of the plant is around $15\ t\ d^{-1}$ which it is not fully exploited due to the low amounts of recyclable waste collected. The selected material is exported (about 20%), used by a small factory built by the municipality for the valorization of the plastic material ($1\ t\ d^{-1}$), or sold to the local private recycling plants, that are about 30 all around La Paz [107] which produce secondary raw materials used within the city or again exported to neighboring countries, such as Perù, Chile and Brazil.

Vermicomposting and the manual sorting plant are activities which are not sufficient to achieve a high recycling rate, but are a first step for starting a recycling process within the MSWM system of La Paz, together with the activities implemented by the informal sector. At the same time, the informal sector applies a process of recyclable waste recovery, which is sent to the local recycling factories or exported to the neighboring countries (about 60%) [108].


**Figure 2.10:** Manual selection plant for recyclable materials located in La Paz (*source: personal photos took during the field in 2016*)

### Informal sector

The informal sector is considered within the WBI, specifically by two qualitative indicators: Quality of 3Rs provision (3R) and provider inclusivity (4P), which assessed its inclusion into the formal recycling chain, and by the quantitative indicator: recycling rate (3), where the amounts of waste recycled are added to those obtained by the formal activities.

The MSW recycling chain of La Paz is taken over, mainly, by the informal recycling sector, which is not recognized by the formal recycling process. La Paz waste pickers, which are the most important actors of the informal recycling chain, are not organized and they mainly collect the recyclable waste from temporary garbage dump sites and storage containers. Although these people are not accredited for the services they render towards MSWM, they continue to reduce the waste inflow into the landfill, providing a service for the community. Such informal collectors are poor people who earn minimum wages to survive. They do not use any precaution or occupational health and safety equipment and are thus exposed to injuries and diseases. Furthermore, they are often perceived as unclean people and a public nuisance, which does not encourage public service providers to include them into the formal MSWM activities, as reported in other studies of other developing contexts [109].

Moreover, within the informal sector, small scale merchants, who work in recycling store shops, act as a link between waste collectors, waste pickers and the established factories. In Figure 2.11 is reported the activity of the waste pickers and of the recycling shops. They constitute an informal market channel useful for the implementation of a recycling policy without the presence of the local authority. In addition, the families involved in the recycling shops gather the recyclable materials as the waste pickers, or receive the material from the citizens who are aware of their organization.

The prices of the recyclable materials are determined by the quality of the waste and the fluctuation of the market, where the waste pickers have no control. The workers of the informal recycling sector have no access to economic funds delivered by the public management and are not organized, thus they could be vulnerable to exploitative arrangements established by those who dictate the values [110].


**Figure 2.11:** Informal recycling implemented in La Paz (*source: personal photos took during the field work from 2016 to 2018*)

NGOs play an important role in organizing the informal sector by documenting and understanding the existing system. The studies conducted by the NGO Swisscontact suggested the importance of the informal activities due to the significant waste quantities that the waste pickers collect during every day. It has been estimated that the informal sector removes 40 t/d of recyclable materials from the waste flows otherwise going to landfill [107, 108]. Based on this data, these activities can be considered the most important recycling chain in La Paz waste markets.

The main issue is the lack of uniform collaboration among private sector, informal waste pickers and the local Government. All these actors are working on developing the recycling chain, but in a fragmented manner. In particular, the informal sector is based on the cooperation between waste pickers and informal recycling shops, which deliver the recyclable waste to the private recycling companies.

**WFA**

The organization of the MSWM activity and the MSW daily quantities generated are depicted in the process flow diagram presented in Figure 2.12. The main waste amounts are presented in order to provide the streams that existed in La Paz in 2016.

Although part of information is not available (i.e. the quantity of waste uncollected) such structure is useful for introducing the WBI and to sum up the situation of the MSWM in La Paz. In particular, the estimation about the waste uncollected by the system has been added. The hypothesis made is that the uncollected waste could be approximated to 5% of the total MSW produced in La Paz, mostly generated in the suburban areas, which represent the 11% of the city's area, uncovered by the collection system.

The information about the quantities collected and exploited by the informal sector derived both from primary data (interviews with members of the local NGOs) and secondary data [107, 108], that is the documents and studies conducted by the same NGO during the years 2008-2013. It should be pointed out that the estimated quantities of uncollected MSW do not consider the amounts collected by the informal sector, but are a qualitative percentage which evaluates the presence of uncollected MSW in the city.

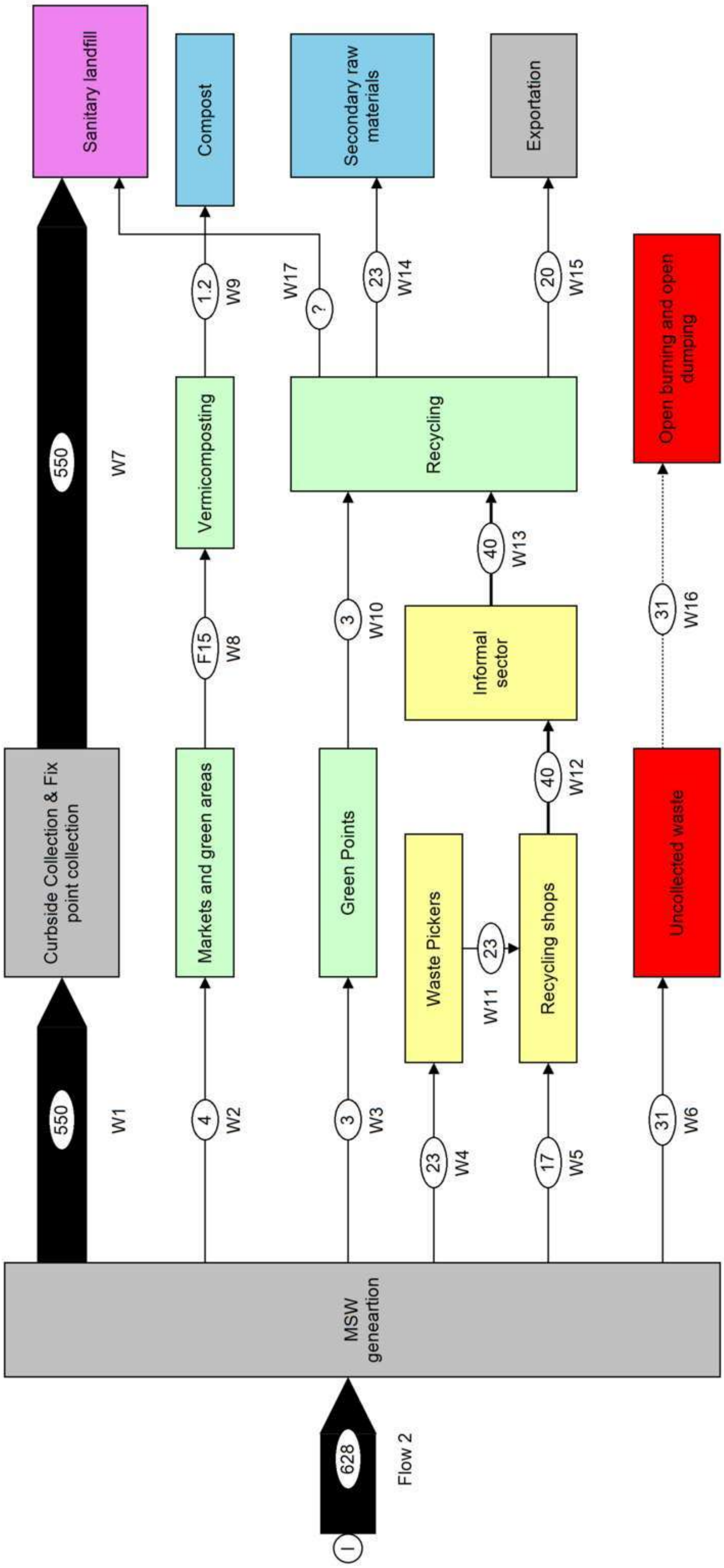


**Figure 2.12:** WFA of the MSWM system of La Paz in 2016 [2]. The functional unit is in tons per day.

| Symbol | Description | Documentation of approach used fro estimation |
|---|---|---|
| I | Daily MSW generated | Sum of the contribution of W2 + W3 + W4 + W5 + W6 |
| W1 | Daily MSW collected by the formal system | Average records of SIREMU available at the final disposal site |
| W2 | organic fraction MSW gathered at the markets, green areas and zoological area | Average records of SIREMU available at the vermicomposting plant |
| W3 | Recyclable waste (paper and cardboard, plastic, glass) gathered at the GP and at the private companies that select the wast voluntary | Records of the GAMLP available at the manual selection plant |
| W4 | Recyclable waste collected informally by the waste pickers | Estimated by a study of Swisscontact in 2008 [107] |
| W5 | Recyclable waste collected by the informal recycling shops | Estimated by a study of Swisscontact in 2008 [107] |
| W6 | MSW uncollected | Estimated by the quantities theoretically produced within the areas without the provision of the collection service |
| W7 | MSW sent to sanitary landfill, equal to W1 | Average of the daily records of SIREMU available at the sanitary landfill |
| W8 | organic fraction MSW sent to the vermicomposting process, equal to W2 | Average of the daily records of SIREMU available at the vermicomposting plant |
| W9 | Amount of compost produced after vermicomposting process | Average of the daily record of SIREMU available at the old open dump site of Mallasa |
| W10 | Amounts of recyclable waste collected and sent to the manual selection plant, equal to W3 | Average of the daily records of the GAMLP available at the plant |
| W11 | Amounts of waste sold by the waste pickers to the informal recycling shops, equal to W4 | Estimated by a study of Swisscontact in 2008 [107] |
| W12 | Amounts of recyclable waste sold to the informal recycling sector and private companies for recycling, W5 + W12 | Estimated by a study of Swisscontact in 2008 [107] |
| W13 | Amounts of recyclable waste informally recycled, equal to W12 | Estimated by a study of Swisscontact in 2008 [107], equal to W13 |
| W14 | Secondary raw materials produced after recycling and exploited in Bolivia | Estimated by the GAMLP |
| W15 | Recyclable waste selected and sent to foreign countries | Estimated by the GAMLP |
| W16 | Uncollected waste disposed of without control, equal to W6 | Estimated in function of the field inspection and in function of the extension of the neighborhoods without waste collection service |
| W17 | Amounts of rejects obtained after the recycling process | Data not available, although the generation is sure |

**Table 2.4:** descriptions of the various flows on the WFA of La Paz in 2016

In Table 2.4 are reported the descriptions of the various flows depicted on the WFA of Figure 2.12. Evaluating the contribution of the informal sector and the pilot projects of the formal recycling processes (GP and recycling facilities), the recycling rate of the city can be assessed at about 8% (without taking into account the uncollected waste which is unknown).

The analysis of the waste collected by the informal sector, the MSW disposed into the landfill and the formal recycling chain introduced into the city, can provide an indication about the MSW generated in the city. The amount of waste, estimated in this study, ranges from $0.63\ kg\ capita^{-1}\ d^{-1}$ to $0.73\ kg\ capita^{-1}\ d^{-1}$. These amounts could be obtained by the range of the population living in the city and the range of

MSW generated. The lower amount of waste produced per inhabitants is estimated without the quantities uncollected (5% of the total amounts), for a total of 597 tons per day, and the higher population estimable (about 950,000), while the higher amount of waste produced per inhabitants ($0.73\ kg\ capita^{-1}\ d^{-1}$) is calculated considering the total amounts estimable (623 tons per day) and the lower population possibly living in the city (about 850,000). This represents only an estimation, since there are no formal systems in place for monitoring the amounts of waste disposed illegally and the ones recycled by the informal sector. Moreover, there are no data about the fluctuation of waste produced during different seasons and no reliable data about the census of the population of La Paz.

### 2.2.3 Results - Governance aspects of MSWM system in La Paz

#### Public education and sensitivity campaigns

The qualitative indicator user inclusivity (4U) evaluates the inclusion of the users for planning suitable MSWM practices and the introduction of sensitivity campaigns for enhancing public awareness.

In La Paz, there is a general lack of public education and awareness related to environmental sustainability and recycling management activities. The waste source separation rate is also low due to the low awareness of the population and the low willingness to adopt such practices. However, when citizens receive information about the benefits of recycling and the method to sort the waste and they are also included into the design of the programs, they are more likely to participate in recycling activities [111].

The introduction of sensitivity campaigns has been reported only by NGOs at pilot projects, while the municipality introduced a simple information system and included some activities for the children on Saturdays at the GP and only into a few areas of the city [108]. Moreover, Universities introduced some sensitivity activities into their programs, and play an important role for developing such awareness actions, involving students in developing the recovery of recyclables from waste.

Finally, there is a feedback mechanism, provided both by the private companies and the local government, useful for the population for expressing their opinion about the service delivered, which is mostly guaranteed to all the citizens of every income level. This represent a good point, since the effort is made to guarantee the equity of the service applied.

#### Financial sustainability

The financial sustainability is expressly evaluated by the qualitative indicator: financial sustainability (5F) of the WBI. This criterion considers the data reliability about public charges and the sustainability of the economic state of the MSWM system.

Public waste charges are collected from indirect taxes, based on electricity bills. Each household pays a monthly fee to the municipality in accordance with their electricity bill, with an average of 12 Bs per month (€1.5; 1.7 USD). Charges to businesses of average dimension (shops, offices and small factories) range from 8.3 to 506.7 Bs (€1 - 61; 1.2 - 73.4 USD), while large industries pay from 291 to 506 Bs (€35 - 61; 42.2 - 73.3 USD) [89]. The total amount is sufficient to cover only 40% of the entire management cost, whereas the low quality of the service rendered, and the lack of effective penalties impacts also the willingness of the waste generators to pay the public charges and follow the regulation introduced by the authorities.

Thus, public charges are not sufficient for maintaining, improving and developing the current service, though most of the population pay for the service. Currently the expense per household is about 0.66% of the yearly income. However, for covering the total MSWM expenses it should be raised to 1.72%, a big effort for the local population. As a result, financing is derived mostly from National Government, international donor partners and NGOs. Indeed, it was the National Government that funded the construction of the landfill in 2004, which significantly improved the pre-existing situation of inadequate waste disposal, and the international donors that introduced studies and activities for improving the MSWM system.

In 2016, the transportation cost of the curbside or fixed-point collection was about 250 Bs/t (€30.1 per t; 36.2 USD/t), whereas the disposal cost was about 100 Bs/t (€12 per t; 14.5 USD/t), comparable with high economic Latin America realities like Chile [112], which highlights the good compliance of the MSWM developed in comparison with other low-middle income countries.

**Legal Framework**

The legal framework at national and local level is the last subject evaluated by the last two indicators of the WBI: adequacy of national solid waste management framework (6N) and local institutional coherence (6L). These qualitative criteria express the level of adequacy of the laws and regulations provided by the local authorities in terms of MSWM and environmental sustainability.

The first national law about MSWM was enacted by the National Government in October 2015. This law was a milestone that encouraged investment in public sanitation. Furthermore, within this law, Polluter-Pays-Principle and Extended Producer Responsibility (EPR) were introduced, although are not fully implemented due to the lack of strong enforcement of regulations and efficient monitoring systems. In 2006, the first local regulation in sanitation was introduced in La Paz. It has been important for regulating the activities of treating wastewater and MSW, with the inclusion of public practices and the application of penalties.

The institutional staff has appropriate academic education and professional experience required for MSWM, although it is not comparable with a developed country due to the lack of doctoral and specialized University courses, funds from the municipality to contact qualified professionals and advanced experiences in the field. However, there is a strong collaboration between NGOs and the municipality.

Bolivian institutional organization suffers from a lack of clear regulations and guidelines. In particular, the lack of a list of best practice, actions and objectives which could be applied according with the law. There is no specific environmental inspectorate to monitor the activities that endanger the environment. The recent MSWM law of 2015 is a good step towards better MSWM practices in Bolivia, but it requires further improvements. The presence of an Environmental Ministry helps refining regulations, introducing a list of regulation and objectives which should be addressed in future plans.

Generally, at local level, La Paz has a good management organization due to the presence of specific Government bodies for each environmental topic and, as regard MSW, for each part of the management system (i.e. monitoring and decision making).

The monitoring system is guaranteed, both at the landfill and for the MSW collection system while the institutional hierarchy is structured and respected. Though, the organization for planning future MSWM strategies is not wide.

**WBI**

The field work, the collaborations with the Bolivian institutions, NGOs and Universities in parallel with the WFA allowed implementing the WBI. In general, local authorities often do not know how well or how badly they are performing and at what level they should set their goals [113]. Furthermore, in environmental topics, the problem is how information can be gathered and assessed in a simple, affordable and rapid manner, while allowing stakeholders to make more informed decisions and to apply new strategies. The WBI gives an answer to these problems, functional for comparing different MSWM of developing and developed country in a single simple scheme.

The radar diagram with all the WBI indicators, in a zero to 100 scale, is presented in Figure 2.13, while the indicators and the summary results are listed in Table 2.5. The results are obtained according to the instructions provided by [88] for evaluating the current MSWM activities applied.

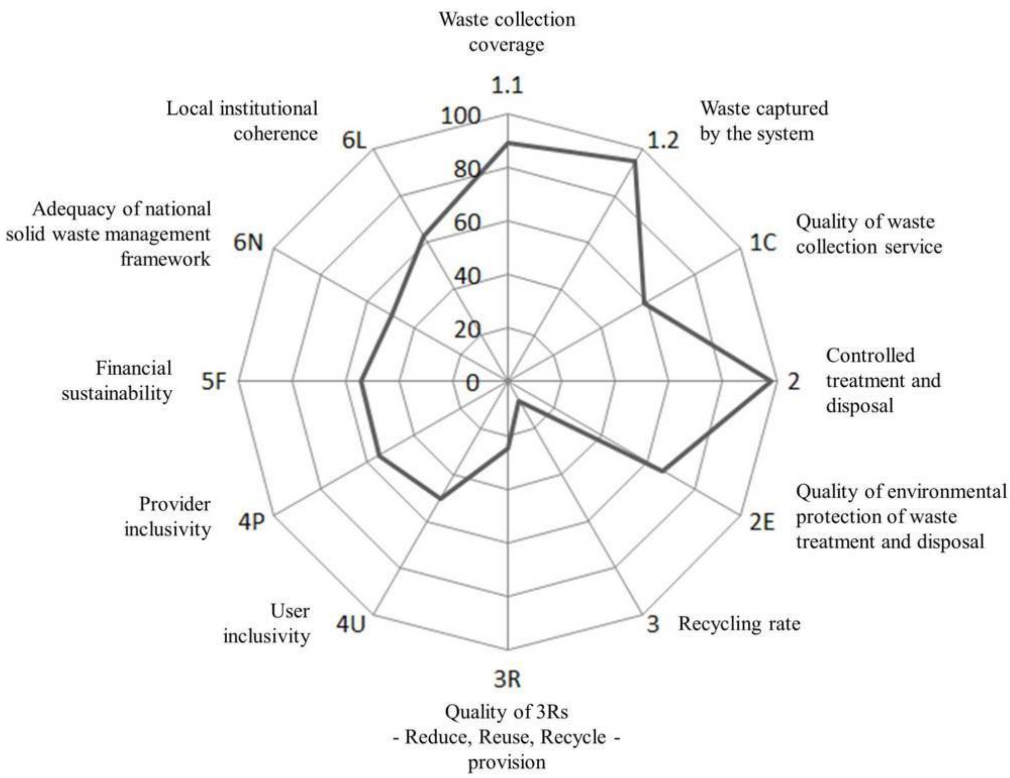


**Figure 2.13:** WBI of the MSWM system of La Paz in 2016 [2].

It is evident that the lower values are achieved concerning the recycling rate, as well as the Governance aspects. The latter is due to the recent application of new regulations, the low financial sustainability and the lack of future MSWM plans.

| Symbol | Indicator | Results - La Paz 2016 |
|---|---|---|
| Physical components | | |
| 1.1 | Waste collection coverage | 89% |
| 1.2 | MSW captured by the SWM and recycling system | 95% |
| 1C | Quality of MSW collection and street cleaning service | 58% |
| 2 | Controlled treatment or disposal | 98% |
| 2E | Degree of environmental protection in waste treatment and disposal | 67% |
| 3 | Recycling rate | 8% |
| 3R | Quality of 3Rs provision | 25% |
| Governance aspects | | |
| 4U | User inclusivity | 50% |
| 4P | Provider inclusivity | 55% |
| 5F | Financial sustainability | 54% |
| 6N | Adequacy of national SWM framework | 50% |
| 6L | Local institutional coherence | 63% |

**Table 2.5:** Summary results for the WBI in La Paz in 2016 [2].

### 2.2.4 Improvements of the MSW from 2016 to 2018

The MSWM system of La Paz has been evaluated during the three years of research. The WBI has been improved following the new systems and regulations implemented in the city. In Figure 2.14 is reported the comparison of the results obtained in 2016, 2017 and 2018, while in Table 2.6 are reported the results of the indicators.

In 2017, the collection system was improved thanks to the commitment of a new private company. The new system imply the location of street containers within the city, in order to reduce the contamination and improve the cleanness of the streets. This improvement is reported by the WBI with the indicator 1C, quality of waste collection service. Moreover, new compactors trucks are also used, making the transportation more safe.

Indicator 2E reports another improvement concerning the management of the sanitary landfill. In particular, the new investment introduced in 2018 for improving the road to the final disposal site, new mostly asphalted. Whereas, indicator 3, about the recycling rate of the city, shows a decrease, since in 2017 the recycling project implemented by Swisscontact ends, and the GAMLP had not sufficient resources for continuing the plan.

Many improvements regards the governance aspects. First of all, the introduction of the first national regulation allows improving the legal framework, so improving indicator 6N. Moreover, at city level, the commitment of the new private company allows introducing a new MSWM plan for improving the recycling rate of the city. Indeed, in 2018, a SC by separate street containers (SSC) has been implemented, in parallel with sensitivity campaigns, supported by private companies, that involved the citizens and in particular children and schools. These improvements ameliorate indicators 4U, 4P and 6L, with changes in recycling behavior and inclusion of the private sector. Thanks the new recycling policy, also the financial sustainability improves, in terms of investments of the private sector, in particular by the waste collection company, and the enhancement in profits due to he sell of the recyclable waste.

Indeed, in 2018, a SC by separate street containers (SSC) has been implemented, in parallel with sensitivity campaigns, supported by private companies, that involved the citizens, children and students. These improvements ameliorate indicators 4U, 4P and 6L, with changes in recycling behavior and inclusion of the private sector. Thanks the new recycling policy, also the financial sustainability improves, in terms of investments of the private sector, in particular by the waste collection company, and the enhancement in profits due to the sell of the recyclable waste.

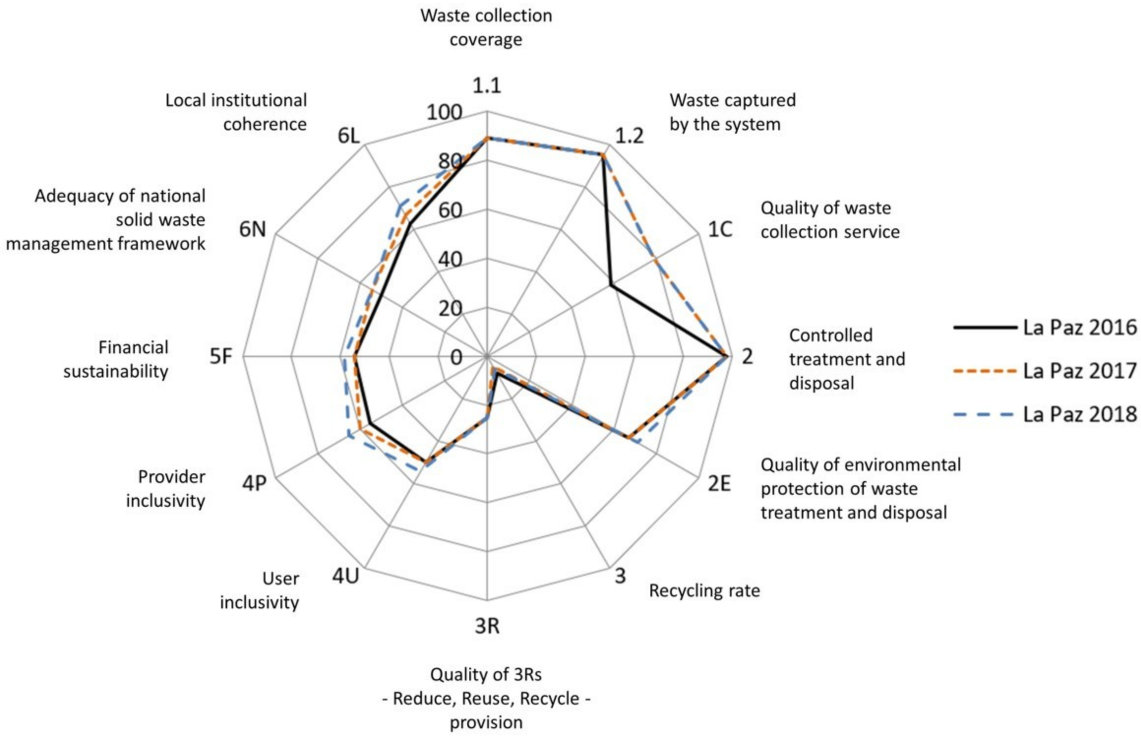


**Figure 2.14:** Comparison of the MSWM of La Paz from 2016 to 2018 with the WBI.

Nevertheless, the 15th of January 2019, the sanitary landfill suffers a collapse that destroyed part of the final disposal site. This incident caused the blocked of the MSW collection, as well as social concern, environmental pollution and economic issues. For 15 days the waste remained in the streets, with health issues do to the presence of vectors of diseases and odors.

The collapse started with the oldest cell of the site, which was the highest in terms of altitude. Than, the fourth, third and second cells collapsed too, run over the cell of the HW and the leachate treatment plant. It has been estimated that about $300,000\,m^3$ of waste collapsed within the site, as visible in Figure 2.15, contaminating the river below.

This issue pose the GAMLP in emergency condition, with the requirement to close the site in 60 days. So, in April 2019, a closing plan should be implemented, choosing another final disposal site. However, this situation demonstrated the requirement to implement different SWM systems in the city, reducing the waste inflow into the final disposal site and improving the technologies for waste valorization. However, La Paz, and generally Bolivia, suffers lack of know-how and financial sustainability for introducing new treatment facilities, making this situation more difficult.

| Symbol | 2016 | 2017 | 2018 |
|---|---|---|---|
| Physical components | | | |
| 1.1 | 89% | 89% | 89% |
| 1.2 | 95% | 95% | 95% |
| 1C | 58.3% | 79% | 79% |
| 2 | 98% | 98% | 98% |
| 2E | 67% | 67% | 71% |
| 3 | 7.9% | 5% | 6% |
| 3R | 25% | 25% | 25% |
| Governance aspects | | | |
| 4U | 50% | 50% | 54% |
| 4P | 55% | 60% | 65% |
| 5F | 54% | 54% | 58% |
| 6N | 50% | 54% | 54% |
| 6L | 63% | 67% | 71% |

**Table 2.6:** Comparison of the results obtained for the WBI in La Paz in 2016, 2017 and 2018.

Many private companies came from all over the world for suggesting inappropriate solutions for exploiting the situation. Various technical commission were formed, and the Ph.D. supported such technical consulting providing indication about the most appropriate technologies and scenarios for the city. In particular, the results reported in this thesis were also provided to the GAMLP for providing a starting point for improving the SWM system of the city. More details will be provided within the chapters of the thesis.

**Figure 2.15:** Collapse of the sanitary landfill in January 2019. Photos took at the end of January 2019 during a technical visit at the final disposal site.

### 2.2.5 Comparison with other cities worldwide

The results obtained can be compared with other case studies published in the last years within the scientific literature, in function of the income level. A literature review has been implemented, in order to find scientific papers where the WFA and the WBI could be implemented. Four articles has been detected. The city where the WBI were implemented are Kerbala, Iraq, Upper-middle income country (GNI 4,770 USD) [115], Bangkok, Thailand, Low-middle income country (GNI 5,720 USD) [96], Accra, Ghana, Low-middle income country (GNI 1,480 USD) [93], Ulaanbaatar, Mongolia, low-middle income country (GNI 3,830 USD) [94]. The results of the researches compared with the case of La Paz of 2018 are reported in Figure 2.16 and Table 2.7.

The graph describes the different rate obtained for each indicator, providing a good overview on how MSWM is developed in different developing cities. The comparison allows confirming the good MSWM system compared with other realities in low-income countries. On one hand, La Paz can be considered as an example for the Bolivian cities, since the MSWM system is quite well developed and comparable with cities in upper-middle income contexts. On the other hand, recycling rate is low and take back programs are still not included in the public management, as typical in low-middle income countries.

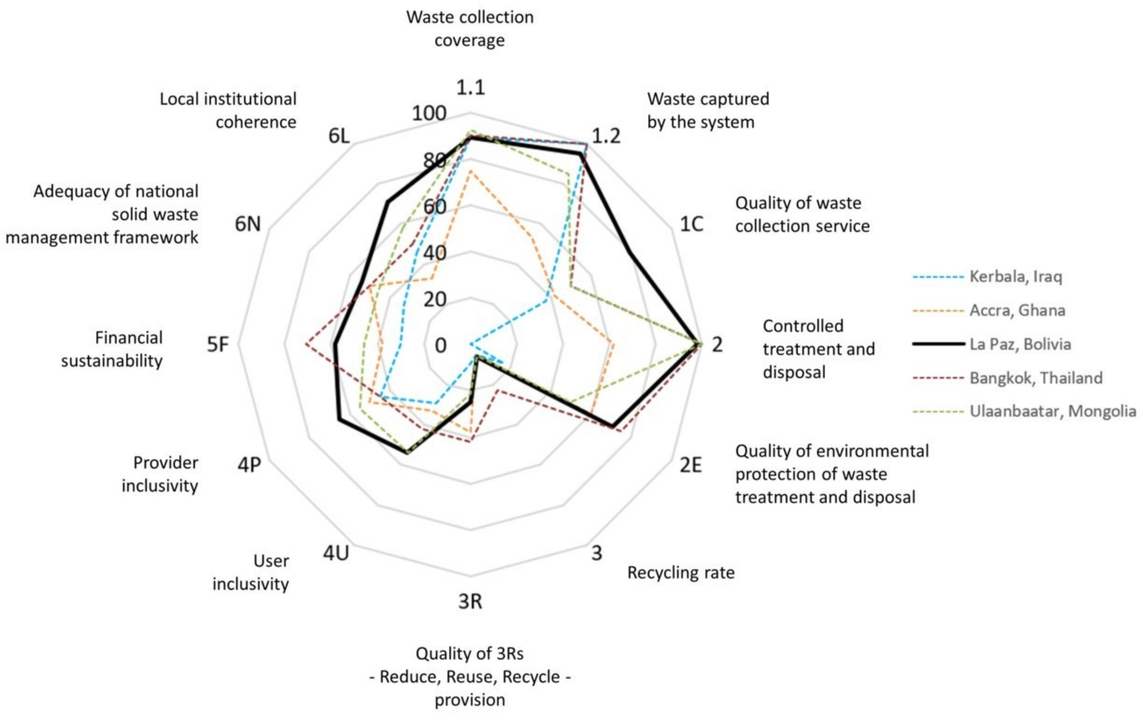


**Figure 2.16:** Comparison of the MSWM of La Paz with low-middle and upper-middle income countries.

However, the governance aspects are encouraging. Seeing Table 2.7 it can be highlighted that La Paz is the best city regarding the inclusion of the private sector and of the population, the implementation of national regulation and MSWM plans. Therefore, these indication provide interesting insights about the feasibility of the implementation of CE plans with international cooperation projects. The new projects can be introduced as example for other regions at national level for boosting sustainability.

| Symbol | La Paz (Bolivia) | Kerbala (Iraq) | Bangkok (Thailand) | Accra (Ghana) | Ulaanbaatar (Mongolia) |
|---|---|---|---|---|---|
| Physical components | | | | | |
| 1.1 | 89% | 89% | 90% | 75% | **93%** |
| 1.2 | 95% | **100%** | **100%** | 53% | 85% |
| 1C | **79%** | 37.5% | 50% | 42% | 50% |
| 2 | 98% | 0% | **100%** | 62% | **100%** |
| 2E | 71% | 16.7% | **75%** | 60% | 50% |
| 3 | 6% | 5% | **23%** | 5% | 5.5% |
| 3R | 25% | 8% | **42%** | 38% | 21% |
| Governance aspects | | | | | |
| 4U | **54%** | 29% | 42% | 33% | **54%** |
| 4P | **65%** | 45% | 45% | 50% | 55% |
| 5F | 58% | 30% | **71%** | 38% | 46% |
| 6N | **54%** | 33% | 50% | 50% | 46% |
| 6L | **71%** | 46% | 50% | 33% | 58% |

**Table 2.7:** Comparison of the results obtained for the WBI for La Paz (2018) and other four developing big cities: Kerbala (Iraq) [115], Bangkok (Thailand) [96], Accra (Ghana) [93], Ulaanbaatar (Mongolia) [94] (in bold, the higher percantege obtained among the cities).

## 2.3 Discussion

Environmental contamination due to solid waste mismanagement is a big issue for developing countries. The review introduced in Section 2.1 reports that the main activity implemented at global level in developing countries is the open burning and open dumping of various waste fractions. Indeed, MSW is only a part of the problem: HW open dumping cause spread of disease and hazards mainly for the waste pickers who operates within the uncontrolled disposal sites, the mismanagement of waste tires is cause of fires and growing of insects and vectors of diseases, while C&D waste pose to serious risk the population surrounding the final disposal sites due to possible landslides. The informal recycling can be seen as an opportunities, however the implementation of plans for its inclusion is challenging. The main issues were detected in developing big cities, where the generation of waste is higher, as well as the difficulties for its collection and treatment. Uncontrolled generation and final disposal generates flows to the water bodies near the cities, improving the contamination of the oceans with marine litters.

The study conducted in La Paz allowed understanding that its MSWM system is mostly improved if compared with other developing big cities of the world. In particular, the regulation system, the implementation of a sanitary landfill and of recycling plans, the presence of a structured management system and the involvement of the population by sensitivities campaigns, allows considering La Paz as a good case study for introducing CE policies and plans.

However, during the years, some issues are still detectable. First of all, the informal sector is unrecognized, however, it is the primary actor responsible for any recycling in the city. Waste pickers work in poor conditions and are mostly made by the weaker part of the population, such as, women, old people and poor citizens. Though, the introduction of new regulations where the informal recycling sector is considered as actor of the recycling system, to date the formal MSWM system still does not includes it. Secondly, the lack of aggregate information is a real important issue for future planning, worsened by the lack of effective communication between various stakeholders, which affects the service provision. Thirdly, lack of financial sustainability is reflected in a persistent absence of funds for improving MSW handling capacities and no policies are implemented. Indeed, the the low fees charged to the citizens and the inadequate collection system of charges still persist in the city. Finally, the study suggested that the primary collection is not efficient in time and transport, neither after the location of the streets containers, since the size of the population and area have an important impact on the cost of MSW collection and disposal to landfill. Indeed, other studies stated that the most critical cost factor is waste transport [116]. Furthermore, in La Paz there are few difficulties in waste transportation systems due to the lack of free land that can be used for temporarily transfer station. On balance, the MSWM system of La Paz can be considered under development and an example for the other Bolivian small towns and big cities, where open dumping is still the solution most applied, underlining that the city is inserted into a low-middle income economy. However, the emergency of the final disposal site poses La Paz at environmental, social and economic risk, affecting the good compliance of the solid waste management system. Solutions should be implemented in short terms, reducing the possibility to implement plans well developed and planned.

The issues detected could be converted in as many activities that should be introduced and investigated for improving the MSWM of the city. First of all, it seems necessary to assess future scenarios for improving the recycling systems. The analysis should be introduced in cooperation with local stakeholders, in order to evaluates the feasibility of the introduction of appropriate technologies. Secondly, the establishment of relevant policies and recycling facilities should be based on consumers behavior and their willingness to pay and to recycle MSW. Therefore, specific studies and surveys are needed for understanding citizens' willingness to pay, recycling behavior, attitudes towards SWM and the economic differences within the districts of the city. For that purpose, a questionnaire survey should be implemented at city level for collecting these information, obtaining useful data for future programs. Then, environmental impacts of future scenarios should be introduced. The tool appropriated for achieving this goals is the LCA. This assessment can provide useful insights about the real impacts introduced by the new scenarios and the technologies thought to be suited for the city. In parallel, a geographical assessment should be introduced trough GIS, in order to evaluate the feasibility of the introduction of different types of collection systems within the city. For assessing the real difficulties for introducing SC plans, a pilot project of SC system in public areas should be implemented, in order to understand main challenges and opportunities of the introduction o recycling plans in public areas, providing solutions for overcome barriers that could be found in a developing context. Finally, other waste streams should be assessed, since the sanitary landfill still store every typology of waste streams. In particular, the healthcare waste, that represent the most hazardous fractions detectable within the sanitary landfill.

These assessments are introduced within this research thanks to an international cooperation network. The intervention of NGOs spread the awareness of the population and allows implementing pilot projects; the University can support the process of international cooperation, finding new partners and providing management plans and new tools; the introduction of private companies interested in investing in this contexts allow encouraging the introduction of new regulations and technologies; the cooperation among foreign Universities, NGOs and private companies could be potential for finding funds delivered specifically to projects for the international cooperation with appropriate researches, monitoring and know-how. Hence, the inclusion of Universities, private companies and informal sector and the introduction of international agreements among universities and NGOs, can be able to support the improvement of the MSWM organization in a multi-stakeholder, low-risk and integrated manner, with the aim to avoid environmental pollution and improve human health, according to the SDGs [117].

# Bibliography


[1] Ferronato N. & Torretta, V. (2019). Waste mismanagmenet in developing countries: A review of global issues. International Journal of Environmnetal Research and Public Health, , .

[2] Ferronato, N., Gorritty Portillo, M. A., Guisbert Lizarazu, E. G., Torretta, V., Bezzi, M., & Ragazzi, M. (2018). The municipal solid waste management of La Paz (Bolivia): Challenges and opportunities for a sustainable development. Waste Management & Research, 36(3), 288-299.

[3] Wilson, D.C., Rodic, L., Modak, P., Soos, R., Carpintero, A., Velis., K., Iyer, M., Simonett, O., 2015. The global waste management outlook. Report. United Nations Environmental Programme, UNEP.

[4] Manaf, L. A., Samah, M. A. A., & Zukki, N. I. M. (2009). Municipal solid waste management in Malaysia: Practices and challenges. Waste management, 29(11), 2902-2906.

[5] Sanneh, E. S., Hu, A. H., Chang, Y. M., & Sanyang, E. (2011). Introduction of a recycling system for sustainable municipal solid waste management: a case study on the greater Banjul area of the Gambia. Environment, development and sustainability, 13(6), 1065-1080.

[6] Seng, B., Kaneko, H., Hirayama, K., & Katayama-Hirayama, K. (2011). Municipal solid waste management in Phnom Penh, capital city of Cambodia. Waste management & research, 29(5), 491-500.

[7] Chiemchaisri, C., Juanga, J. P., & Visvanathan, C. (2007). Municipal solid waste management in Thailand and disposal emission inventory. Environmental monitoring and assessment, 135(1-3), 13-20.

[8] Al-Khatib, I. A., Hammad, A. A., Sharkas, O. A., & Sato, C. (2015). Public concerns about and perceptions of solid waste dump sites and selection of sanitary landfill sites in the West Bank, Palestinian territory. Environmental monitoring and assessment, 187(4), 186.

[9] Aderoju, O. M., Dias, G. A., & Gonçalves, A. J. (2018). A GIS-based analysis for sanitary landfill sites in Abuja, Nigeria. Environment, Development and Sustainability, 1-24.

[10] dos Muchangos, L. S., Tokai, A., & Hanashima, A. Greenhouse gas emissions and cost assessments of municipal solid waste treatment and final disposal in Maputo City. Environment, Development and Sustainability, 1-19.

[11] Torretta, V., Ferronato, N., Katsoyiannis, I., Tolkou, A., & Airoldi, M. (2016). Novel and conventional technologies for landfill leachates treatment: A review. Sustainability, 9(1), 9.

[12] Karak, T., Bhattacharyya, P., Das, T., Paul, R. K., & Bezbaruah, R. (2013). Non-segregated municipal solid waste in an open dumping ground: a potential contaminant in relation to environmental health. International Journal of Environmental Science and Technology, 10(3), 503-518.

[13] Biswas, A. K., Kumar, S., Babu, S. S., Bhattacharyya, J. K., & Chakrabarti, T. (2010). Studies on environmental quality in and around municipal solid waste dumpsite. Resources, Conservation and Recycling, 55(2), 129-134.

[14] Parameswari, K., Padmini, T. K., & Mudgal, B. V. (2015). Assessment of soil contamination around municipal solid waste dumpsite. Indian Journal of Science and Technology, 8(36).

[15] Prechthai, T., Parkpian, P., & Visvanathan, C. (2008). Assessment of heavy metal contamination and its mobilization from municipal solid waste open dumping site. Journal of Hazardous Materials, 156(1-3), 86-94.

[16] Kanmani, S., & Gandhimathi, R. (2013). Assessment of heavy metal contamination in soil due to leachate migration from an open dumping site. Applied Water Science, 3(1), 193-205.

[17] Rizo, O. D., Merlo, M. H., Castillo, F. E., & López, J. A. (2012). Assessment of metal pollution in soils from a former Havana (Cuba) solid waste open dump. Bulletin of environmental contamination and toxicology, 88(2), 182-186.

[18] Ihedioha, J. N., Ukoha, P. O., & Ekere, N. R. (2017). Ecological and human health risk assessment of heavy metal contamination in soil of a municipal solid waste dump in Uyo, Nigeria. Environmental geochemistry and health, 39(3), 497-515.

[19] Reyes-López, J. A., Ramírez-Hernández, J., Lázaro-Mancilla, O., Carreón-Diazconti, C., & Garrido, M. M. L. (2008). Assessment of groundwater contamination by landfill leachate: A case in México. Waste Management, 28, S33-S39.

[20] Ashraf, M.A., Yusoff, I., Yusof, M., & Alias, Y. (2013). Study of contaminant transport at an open-tipping waste disposal site. Environmental Science and Pollution Research, 20(7), 4689-4710. - Malaysia -

[21] El-Salam, M.M.A., & Abu-Zuid, G. I. (2015). Impact of landfill leachate on the groundwater quality: A case study in Egypt. Journal of advanced research, 6(4), 579-586.

[22] Efroymson, R.A. (1997). Toxicological benchmarks for screening potential contaminants of concern for effects on terrestrial plants: 1997 Revision. Oak Ridge National Laboratory.

[23] WHO - World Health Organization (2006) Guidelines for drinking-water quality (electronic resource). Available online at $https://www.who.int/water_sanitation_health/dwq/gdwq0506.pdf$

[24] Cheshire, A., & Adler, E. (2009). UNEP/IOC guidelines on survey and monitoring of marine litter. Regional Seas Reports and Studies No. 186 IOC Technical Series No. 83

[25] Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., ... & Law, K. L. (2015). Plastic waste inputs from land into the ocean. Science, 347(6223), 768-771.

[26] Andrady, A. L. (2011). Microplastics in the marine environment. Marine pollution bulletin, 62(8), 1596-1605.

[27] do Sul, J. A. I., & Costa, M. F. (2014). The present and future of microplastic pollution in the marine environment. Environmental pollution, 185, 352-364.

[28] de Haan, W.P., Sanchez-Vidal, A., Canals, M., & Party, N. S. S. (2019). Floating microplastics and aggregate formation in the Western Mediterranean Sea. Marine Pollution Bulletin, 140, 523-535.

[29] The Ocean Cleanup, the largest cleanup in history. Project available online: $https://www.theoceancleanup.com/$

[30] Minh, N. H., Minh, T. B., Watanabe, M., Kunisue, T., Monirith, I., Tanabe, S., ... & Tuyen, B. C. (2003). Open dumping site in Asian developing countries: a potential source of polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans. Environmental science & technology, 37(8), 1493-1502.

[31] Bastian, L., Yano, J., Hirai, Y., & Sakai, S. I. (2013). Behavior of PCDD/Fs during open burning of municipal solid waste in open dumping sites. Journal of Material Cycles and Waste Management, 15(2), 229-241.

[32] Ragazzi, M., Tirler, W., Angelucci, G., Zardi, D., & Rada, E. C. (2013). Management of atmospheric pollutants from waste incineration processes: the case of Bozen. Waste Management & Research, 31(3), 235-240.

[33] Chartier, Y. (Ed.). (2014). Safe management of wastes from health-care activities. World Health Organization.

[34] Hossain, M. S., Santhanam, A., Norulaini, N. N., & Omar, A. M. (2011). Clinical solid waste management practices and its impact on human health and environment–A review. Waste management, 31(4), 754-766.

[35] Al-Khatib, I.A., & Sato, C. (2009). Solid health care waste management status at health care centers in the West Bank–Palestinian Territory. Waste management, 29(8), 2398-2403.

[36] Coker, A., Sangodoyin, A., Sridhar, M., Booth, C., Olomolaiye, P., & Hammond, F. (2009). Medical waste management in Ibadan, Nigeria: Obstacles and prospects. Waste management, 29(2), 804-811.

[37] Patwary, M. A., O'Hare, W. T., & Sarker, M. H. (2011). An illicit economy: Scavenging and recycling of medical waste. Journal of environmental management, 92(11), 2900-2906.

[38] Patwary, M. A., O'Hare, W. T., & Sarker, M. H. (2011). Assessment of occupational and environmental safety associated with medical waste disposal in developing countries: a qualitative approach. Safety science, 49(8-9), 1200-1207.

[39] Windfeld, E. S., & Brooks, M. S. L. (2015). Medical waste management–A review. Journal of environmental management, 163, 98-108.

[40] Kumar, A., Holuszko, M., & Espinosa, D. C. R. (2017). E-waste: an overview on generation, collection, legislation and recycling practices. Resources, Conservation and Recycling, 122, 32-42.

[41] Balde, K., Wang, F., Huisman, J., Kuehr, R., 2015. The Global E-Waste Monitor.United Nations University, IAS – SCYCLE, Bonn, Germany.

[42] Garlapati, V. K. (2016). E-waste in India and developed countries: Management, recycling, business and biotechnological initiatives. Renewable and Sustainable Energy Reviews, 54, 874-881.

[43] WorldLoop, changing the e-waste cycle, (2013). Illegal Flows, from $http://worldloop.org/e-waste/illegal-flows/$.

[44] Olafisoye, O. B., Adefioye, T., & Osibote, O. A. (2013). Heavy metals contamination of water, soil, and plants around an electronic waste dumpsite. Pol. J. Environ. Stud, 22(5), 1431-1439.

[45] Nava-Martínez., E. C., Flores-García, E., Espinoza-Gomez, H., & Wakida, F. T. (2012). Heavy metals pollution in the soil of an irregular urban settlement built on a former dumpsite in the city of Tijuana, Mexico. Environmental Earth Sciences, 66(4), 1239-1245.

[46] Zand, A. D., & Abduli, M. A. (2008). Current situation of used household batteries in Iran and appropriate management policies. Waste Management, 28(11), 2085-2090.

[47] Osibanjo, O., & Nnorom, I. C. (2007). The challenge of electronic waste (e-waste) management in developing countries. Waste Management & Research, 25(6), 489-501.

[48] Cucchiella, F., D'Adamo, I., Koh, S. L., & Rosa, P. (2015). Recycling of WEEEs: An economic assessment of present and future e-waste streams. Renewable and Sustainable Energy Reviews, 51, 263-272.

[49] Ikhlayel, M. (2018). An integrated approach to establish e-waste management systems for developing countries. Journal of Cleaner Production, 170, 119-130.

[50] , L.Y., Tam, V.W.Y., Tam, C.M., Drew, D., 2004. Mapping approach for examining waste management on construction sites. Journal of Construction Engineering and Management 130 (4), 472–481.

[51] Yang, H., Xia, J., Thompson, J. R., & Flower, R. J. (2017). Urban construction and demolition waste and landfill failure in Shenzhen, China. Waste management, 63, 393-396.

[52] Thongkamsuk, P., Sudasna, K., & Tondee, T. (2017). Waste generated in high-rise buildings construction: A current situation in Thailand. Energy Procedia, 138, 411-416.

[53] Kofoworola, O.F., & Gheewala, S. H. (2009). Estimation of construction waste generation and management in Thailand. Waste management, 29(2), 731-738.

[54] Lockrey, S., Nguyen, H., Crossin, E., & Verghese, K. (2016). Recycling the construction and demolition waste in Vietnam: opportunities and challenges in practice. Journal of Cleaner Production, 133, 757-766.

[55] Esa, M.R., Halog, A., & Rigamonti, L. (2017). Developing strategies for managing construction and demolition wastes in Malaysia based on the concept of circular economy. Journal of Material Cycles and Waste Management, 19(3), 1144-1154.

[56] Manowong, E. (2012). Investigating factors influencing construction waste management efforts in developing countries: an experience from Thailand. Waste Management & Research, 30(1), 56-71.

[57] Rajesh, K., Dhanasekaran, D., & Tyagi, B. K. (2013). Survey of container breeding mosquito larvae (Dengue vector) in Tiruchirappalli district, Tamil Nadu, India. Journal of Entomology and Zoological Studies, 1(6), 88-91.

[58] Shakya, P. R., Shrestha, P., Tamrakar, C. S., & Bhattarai, P. K. (2008). Studies on potential emission of hazardous gases due to uncontrolled open-air burning of waste vehicle tyres and their possible impacts on the environment. Atmospheric Environment, 42(26), 6555-6559.

[59] Cooper, J. A. (1980). Environmental impact of residential wood combustion emissions and its implications. Journal of the Air Pollution Control Association, 30(8), 855-861.

[60] Artínano, B., Gómez-Moreno, F. J., Díaz, E., Amato, F., Pandolfi, M., Alonso-Blanco, E., ... & Alastuey, A. (2017). Outdoor and indoor particle characterization from a large and uncontrolled combustion of a tire landfill. Science of the Total Environment, 593, 543-551.

[61] Singh, A., Spak, S. N., Stone, E. A., Downard, J., Bullard, R. L., Pooley, M., ... & Beardsley, D. (2015). Uncontrolled combustion of shredded tires in a landfill–Part 2: Population exposure, public health response, and an air quality index for urban fires. Atmospheric Environment, 104, 273-283.

[62] Park, J., Díaz-Posada, N., & Mejía-Dugand, S. (2018). Challenges in implementing the extended producer responsibility in an emerging economy: The end-of-life tire management in Colombia. Journal of Cleaner Production, 189, 754-762.

[63] Rao, G. T., Rao, V. G., Ranganathan, K., Surinaidu, L., Mahesh, J.,& Ramesh, G. (2011). Assessment of groundwater contamination from a hazardous dump site in Ranipet, Tamil Nadu, India. Hydrogeology Journal, 19(8), 1587-1598.

[64] Steuer, B., Ramusch, R., & Salhofer, S. P. (2018). Can Beijing's informal waste recycling sector survive amidst worsening circumstances?. Resources, Conservation and Recycling, 128, 59-68.

[65] Uddin, S. M. N., & Gutberlet, J. (2018). Livelihoods and health status of informal recyclers in Mongolia. Resources, Conservation and Recycling, 134, 1-9.

[66] Kasinja, C., & Tilley, E. (2018). Formalization of Informal Waste Pickers' Cooperatives in Blantyre, Malawi: A Feasibility Assessment. Sustainability, 10(4), 1149.

[67] Nemadire, S., Mapurazi, S., & Nyamadzawo, G. (2017). Formalising informal solid waste recycling at the Pomona dumpsite in Harare, Zimbabwe. In Natural Resources Forum (Vol. 41, No. 3, pp. 167-178). Oxford, UK: Blackwell Publishing Ltd.

[68] Romallosa, A., & Kraft, E. (2017). Feasibility of Biomass Briquette Production from Municipal Waste Streams by Integrating the Informal Sector in the Philippines. Resources, 6(1), 12.

[69] Black, M., Karki, J., Lee, A. C. K., Makai, P., Baral, Y. R., Kritsotakis, E. I., ... & Heckmann, A. F. (2019). The health risks of informal waste workers in the Kathmandu Valley: a cross-sectional survey. Public health, 166, 10-18.

[70] Rockson, G. N., Kemausuor, F., Seassey, R., & Yanful, E. (2013). Activities of scavengers and itinerant buyers in Greater Accra, Ghana. Habitat International, 39, 148-155.

[71] Vergara, S.E., Damgaard, A., & Gomez, D. (2016). The efficiency of informality: quantifying greenhouse gas reductions from informal recycling in Bogotá, Colombia. Journal of Industrial Ecology, 20(1), 107-119.

[72] Jaligot, R., Wilson, D.C., Cheeseman, C.R., Shaker, B., Stretz, J., 2016. Applying value chain analysis to informal sector recycling: A case study of the Zabaleen. Resour. Conserv. Recycl. 114, 80–91.

[73] Uddin, S.M.N., Gutberlet, J., 2018. Livelihoods and health status of informal recyclers in Mongolia. Resour. Conserv. Recycl.

[74] Kumar, A., Samadder, S.R., Kumar, N., Singh, C., 2018. Estimation of the generation rate of different types of plastic wastes and possible revenue recovery from informal recycling. Waste Manag.

[75] Vergara, S.E., Damgaard, A., Gomez, D., 2016. The Efficiency of Informality: Quantifying Greenhouse Gas Reductions from Informal Recycling in Bogotá, Colombia. J. Ind. Ecol.

[76] Ghosh, S.K., Agamuthu, P., 2018. Circular economy: The way forward. Waste Manag. Res.

[77] Sauvé, S., Bernard, S., Sloan, P., 2016. Environmental sciences, sustainable development and circular economy: Alternative concepts for trans-disciplinary research. Environ. Dev.

[78] Ghosh, S.K., Agamuthu, P., 2018. Circular economy: The way forward. Waste Manag. Res.

[79] Fiksel, J., Lal, R., 2018. Transforming waste into resources for the Indian economy. Environ. Dev. https://doi.org/10.1016/j.envdev.2018.02.002

[80] Reike, D., Vermeulen, W.J.V., Witjes, S., 2018. The circular economy: New or Refurbished as CE 3.0? — Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options. Resour. Conserv. Recycl. 135, 246–264.

[81] Velis, C. (2017). Waste pickers in Global South: Informal recycling sector in a circular economy era. Waste Management & Research. Editorial

[82] Srivastava, V., Ismail, S. A., Singh, P., & Singh, R. P. (2015). Urban solid waste management in the developing world with emphasis on India: challenges and opportunities. Reviews in Environmental Science and Bio/Technology, 14(2), 317-337.

[83] Ziraba, A. K., Haregu, T. N., & Mberu, B. (2016). A review and framework for understanding the potential impact of poor solid waste management on health in developing countries. Archives of Public Health, 74(1), 55.

[84] Ikhlayel, M. (2018). Development of management systems for sustainable municipal solid waste in developing countries: A systematic life cycle thinking approach. Journal of Cleaner Production, 180, 571-586.

[85] Prieto-Sandoval, V., Jaca, C., & Ormazabal, M. (2018). Towards a consensus on the circular economy. Journal of Cleaner Production, 179, 605-615.

[86] Geissdoerfer, M., Savaget, P., Bocken, N. M., & Hultink, E. J. (2017). The Circular Economy–A new sustainability paradigm?. Journal of cleaner production, 143, 757-768.

[87] Ilić, M., & Nikolić, M. (2016). Drivers for development of circular economy–A case study of Serbia. Habitat International, 56, 191-200.

[88] Wilson DC, Rodic L, Cowing MJ, Velis CA, Whiteman AD, Scheinberg, A, ... Oelz B (2015) 'Wasteaware' benchmark indicators for integrated sustainable waste management in cities. Waste Management 35: 329-342.

[89] Ministerio de Medio Ambiente y Agua – MMAyA (2011) Viceministerio de agua potable y saneamiento básico. Diagnóstico de la gestión de residuos sólidos en el Departamento de La Paz, Dirección general de gestión integral de residuos sólidos.

[90] Al Sabbagh MK, Velis CA, Wilson DC and Cheeseman CR (2012) Resource management performance in Bahrain: a systematic analysis of municipal waste management, secondary material flows and organizational aspects. Waste Management & Research 30(8): 813-824.

[91] Sim NM, Wilson DC, Velis CA and Smith SR (2013). Waste management and recycling in the former Soviet Union: The City of Bishkek, Kyrgyz Republic (Kyrgyzstan). Waste Management & Research 31:106-125.

[92] Masood M, Barlow CY and Wilson DC (2014) An assessment of the current municipal solid waste management system in Lahore, Pakistan. Waste Management & Research 32(9): 834-847.

[93] Oduro-Appiah, K., Scheinberg, A., Mensah, A., Afful, A., Boadu, H. K., & de Vries, N. (2017). Assessment of the municipal solid waste management system in Accra, Ghana: A 'Wasteaware'benchmark indicator approach. Waste Management & Research, 35(11), 1149-1158.

[94] Byamba, B., & Ishikawa, M. (2017). Municipal solid waste management in Ulaanbaatar, Mongolia: Systems analysis. Sustainability, 9(6), 896.

[95] Rana, R., Ganguly, R., & Gupta, A. K. (2015). An assessment of solid waste management system in Chandigarh city, India. Electronic Journal of Geotechnical Engineering, 20, 1547-1572.

[96] Chanhthamixay, B., Vassanadumrongdee, S., & Kittipongvises, S. (2017). Assessing the Sustainability Level of Municipal Solid Waste Management in Bangkok, Thailand by Wasteaware Benchmarking Indicators. Applied Environmental Research, 39(3), 49-61.

[97] Jacob P, Kashyap P, Suparat T and Visvanathan C (2014). Dealing with emerging waste streams: Used tyre assessment in Thailand using material flow analysis. Waste Management & Research, 32(9), 918-926.

[98] dos Muchangos LS, Tokai A and Hanashima A (2017) Application of material flow analysis to municipal solid waste in Maputo City, Mozambique. Waste Management & Research 35(3): 253-266.

[99] Ferronato N, D'Avino C, Ragazzi M, Torretta V and De Feo G (2017) Social Surveys about Solid Waste Management within Higher Education Institutes: A Comparison. Sustainability 9(3): 391.

[100] Manga VE, Forton OT and Read AD (2008) Waste management in Cameroon: A new policy perspective? Resources, conservation and recycling 52(4): 592-600.

[101] Okot-Okumu J and Nyenje R (2011) Municipal solid waste management under decentralization in Uganda. Habitat International 35(4): 537-543.

[102] Aleluia J and Ferrão P (2016) Characterization of urban waste management practices in developing Asian countries: A new analytical framework based on waste characteristics and urban dimension. Waste Management.

[103] Kinobe JR, Gebresenbet G, Niwagaba CB and Vinnerås B (2015) Reverse logistics system and recycling potential at a landfill: A case study from Kampala City. Waste Management 42: 82-92.

[104] Choque PA (2012). Manual de lombricultura y compostaje como parte de la gestión del cierre del relleno sanitario de Mallasa. TERSA, Swisscontact, Sistema de regulación y supervisión Municipal.

[105] Lalander CH, Komakech, AJ and Vinnerås B (2015) Vermicomposting as manure management strategy for urban small-holder animal farms–Kampala case study. Waste Management 39: 96-103.

[106] Ramos S.J. (2016). El plan de cierre del relleno sanitario de Mallasa: evaluación y soluciones sobre contaminación de suelos mediante el uso de la lombricultura.

[107] Swisscontact (2008). Estudio de gestión de residuos sólidos reciclables, para la ciudad de La Paz. Informe final.

[108] Swisscontact (2013). Ecovecindarios, trabajamos en comunidad. Memoria 2009-2012.

[109] Ezeah C, Fazakerley JA and Roberts CL (2013) Emerging trends in informal sector recycling in developing and transition countries. Waste Management 33(11): 2509–2519.

[110] Paul JG, Arce-Jaque J, Ravena N and Villamor SP (2012) Integration of the informal sector into municipal solid waste management in the Philippines – What does it need? Waste Management 32(11): 2018-2028.

[111] Sidique SF, Lupi F and Joshi SV (2010). The effects of behavior and attitudes on drop-off recycling activities. Resources, Conservation and Recycling, 54(3), 163-170.

[112] Vasquez O. (2005) Simulation model of household solid waste management in the Metropolitan Region of Chile. Revista de dinámica de sistemas 1(1): 27-52

[113] Zotos G, Karagiannidis A, Zampetoglou S, et al. (2009) Developing a holistic strategy for integrated waste management within municipal planning: Challenges, policies, solutions and perspectives for Hellenic municipalities in the zero-waste, low-cost direction. Waste Management 29: 1686–1692.

[114] Guerrero LA, Maas G and Hogland W (2013) Solid waste management challenges for cities in developing countries. Waste management 33(1): 220-232.

[115] Abdulredha, M., Kot, P., Al Khaddar, R., Jordan, D., & Abdulridha, A. (2018). Investigating municipal solid waste management system performance during the Arba'een event in the city of Kerbala, Iraq. Environment, Development and Sustainability, 1-24.

[116] Lohri, C. R., Camenzind, E. J., & Zurbrügg, C. (2014). Financial sustainability in municipal solid waste management–Costs and revenues in Bahir Dar, Ethiopia. Waste Management, 34(2), 542-552.

[117] Rodic L and Wilson DC (2017) Resolving Governance Issues to Achieve Priority Sustainable Development Goals Related to Solid Waste Management in Developing Countries. Sustainability 9(3): 404.

# Chapter 3

# Sustainable solutions and technologies: Assessing future MSWM scenarios

*- We are the first generation to be able to end poverty, and the last generation that can take steps to avoid the worst impacts of climate change -*
*Ban Ki-moon*

## Introduction

This Chapter is focused on the assessment of the most appropriate methods and technologies for collecting and treating MSW in developing countries. It is divided in two main sections. The first section reviewed the main technologies available worldwide, discussing the most suitable for low-middle income countries. A CE model, developed in this research, is introduced in order to suggest an integrated plan for improving recycling and sustainability in developing big cities. The model has been published in 2019 in the "*Journal of Environmental Management*" in order to discuss opportunities and challenges for implementing the model in Bolivia [1]. In this research the model is provided for commenting and critically assessing the main opportunities for the city of La Paz regarding the implementation of recycling policies.

The second section introduces a preliminary assessment of the scenarios that could be introduced in La Paz, according to the collection and treatment technologies explained within the first section of this Chapter. The GWP, recycling rate (RR) and financial sustainability of each MSWM scenario are presented, in parallel with a questionnaire survey submitted to the experts of La Paz. A MCDA is also used for assessing the results and providing final ranking, discussed in function of the results of a sensitivity analysis. The work presented in the second section was published in the "*Environmental Development*" Journal in 2019 [2]. Finally, at the end of the Chapter, the scenarios obtained with the MCDA and the CE model are critically commented, in order to evaluate the main requirements for introducing the CE in La Paz and the theoretical methods neeed for better assessing the MSWM scenario most suited for the city in terms of social, economic and environmental issues.

## 3.1 The introduction of the CE model in developing countries: Opportunities and main issues

Part of this section refers to the article *"Introduction of the circular economy within developing regions: A comparative analysis of advantages and opportunities for waste valorization" - Journal of Environmental Management* (Ferronato, N., Rada, E. C., Portillo, M. A. G., Cioca, L. I., Ragazzi, M., and Torretta, V. - 2019).

### 3.1.1 Waste Collection and transportation

SWM systems include generation, transport, treatment, and disposal of waste. Of these, the collection methods influence the rest of the operations, affecting the overall system. Collection is a costly process of the SWM because of the labor intensity and massive use of trucks, becoming more complex due to the massive urbanization. In low-middle income countries waste is mainly manually handled and accounts for about 80% of all costs associated with SWM [3].

Waste collection and transport are the most important activities for avoiding nuisance and public health issues. The implementation of a sustainable collection system involves the finalization of collection routes, training of personnel, providing information to the population, and maintenance of facilities. High service standards should be combined with high rates of material recovery and recycling. This can be obtained minimizing multiple manual handling and separating waste components with high purity, considering the informal recycling streams.

The responsibilities for waste collection differ depending on where the waste is generated. Operating costs are minimized and maximum value is achieved when collection rounds are well designed. Due to the large number of variables, designing efficient solid waste collection is a complex task and, therefore, it should receive attention for improving performances and reducing costs [4].

#### Source segregation

The selection of recyclable waste is implemented according to specific treatment requirements. It needs high degrees of households involvement and high collection costs. It is a prerequisite for efficient recycling providing clean feed-stock. Source separation includes the selective collection of paper, glass, metal, plastics and OFMSW, combined for reducing recycling costs.

The quality of the segregation depends on the selection implemented at the source, involving public participation with education and communication programs. Special vehicles are needed for SC, as well as public information and cooperation among formal and informal collection. The primary benefit of SC is the revenue generation from selling recyclable waste. Secondly, solid waste recycling allows reducing environmental impacts, preventing the use of raw materials and energy. It also reduces the requirements for waste disposal, increasing the sanitary landfill useful life [3].

Pay as you through (PAYT) schemes are adopted for improving the formal SC. However, variable charging for residual waste collection according to volumes or weight is implemented mainly in high-income countries. Alternative scheme is to provide some form of incentives, with coupons or free markets actions [4].

### Waste storage

In developing countries, in the absence of waste storage at source, the solid waste is thrown on the street, generating small open dumps around the city. Plastic bags or containers are typically required for waste storage, specifically designed to fit the truck-mounted loading mechanisms. The type of containers, their location, the collection method and public acceptance should be considered for planning the storage system.

The kind of container used, as well as the transportation procedure, is function on the characteristics of the waste, collection frequency and the space available for placing the containers. In particular, containers should be of adequate capacity, easy to identify in terms of color, shape and marking, easy to repair and appropriate for preventing the access of waste pickers. Other methods consider the community storage, designed for facilitating secondary collection, and litter bins, provided on important streets, markets and public areas, at a distance ranging from 25m to 250m [3].

### Waste collection

Waste collection is often divided into primary and secondary service. Primary collection is the means by which waste is collected from its source and transported to community storage or transfer stations, while secondary collection is the collection from secondary storage areas to treatment facilities or final disposal sites. The way that waste is collected determines which SWM options can be used. For planning an efficient solid waste collection system, the priority is to identify the collection and transfer options, the collection equipment, the collection routes and schedules, and the monitor system performance [3].

Different collection systems can be implemented citeSurampalli.3:

- Door to door (DtD) and curbside collection, where the waste is collected outside properties by containers and picked up by passing vehicles;
- block collection, where collectors sounds rings bell and waits at specified locations for residents to bring waste to the collection vehicles;
- drop of centers, where the residents are required to dump their waste at a specific location, preferably separated;
- and shared street containers, where waste generators through their waste into containers which are emptied or removed.

DtD collection facilitates maximum households separation, increasing participation behavior. However, in low-middle income countries, the collection schedules usually are not comply, resulting in street open dumping of waste. Therefore, efficient curbside collection is mainly implemented in high-income countries. The collection rate is influenced by the type of collection system adopted, which is influenced by the income of the country. Low income countries tend to have low collection rates (about 40%), while high income countries achieved an average of 98% [3].

Larger collection vehicles offer significant advantages in terms of costs. However, lack of covering and manual loading often leads to littering and collection workers significant strains. Good maintenance of vehicles and the use of compactor/atomized trucks significantly improve the collection service, in parallel with planning of collection routes, which allows maximizing the productivity of the SWM system.

**Informal collection and waste pickers**

As introduced in Section 2.1.2, along with the formal MSWM system, there is another unofficial sector consisting on people that collect and recycle informally recyclable waste streams. This is a low-technology, low-pay, unregulated work, often implemented by families or individuals groups. After collection, the waste pickers sell the waste to other dealers and recycling shops. It is an activity mainly carried out by poor and marginalized social groups, who pick waste for income generation. Generally, there are three categories of waste pickers: street waste pickers, municipal waste pickers, and dump site waste pickers [5]. The itinerant street waste pickers buy or collect the waste from citizens, dustbins and street containers, moving around the streets with baskets or pushed carts. Municipal waste pickers collect the waste from vehicles, or are organized in shops for collecting or buying the recyclable waste. Finally, the last category live-in or live-out sanitary landfills or open dump sites, where they pick the waste from the final disposal sites.

Informal recycling brings significant economic benefits to developing cities and low-income towns, minimizing the waste inflow into final disposal sites and generating a new economy of the waste. However, their living conditions, limited access to healthcare facilities and their low public consideration, increase their exposure to health risks, injuries and bite of animals.

Local authorities and policy-makers, supported by international NGO and local stakeholders, can organize street waste pickers, motivating them to stop collecting the waste from containers, gathering the recyclable waste from households and waste generators. The organization of cooperatives and groups formalized and included in the formal SC system allow improving the MSWM system, improving recycling rates with the involvement of local activities [3].

### 3.1.2 Waste treatment and final disposal

Recycling refers to the conversion of waste into valuable resources. In an integrated SWM system, recycling is listed near the top of a hierarchy, after reduce and reuse (3Rs). However, recycling alone is not enough for transforming solid waste in valuable resources, due to the various fractions forming part the SWM system. Therefore, resource recovery is also important, which refers to the conversion of waste in energy, also called waste-to-energy (WtE).Through waste recovery, the products are converted in valuable resources, saving virgin materials and minimizing waste final disposal.

To achieve efficient resource recovery from waste, after appropriate SC, two other steps are required: processing (or treatment) to materials or energy, and using the products obtained by consumers or industries, which implies the presence of a formal (or informal) market for their exploitation. Therefore, integrated assessment and use of treatment facilities is required for each waste fraction and flow. In general, the treatment processes are summarized in three groups [6]:

- Mechanical treatment. It involves size reduction, sorting and compaction. It can be implemented in separate facilities or combined with thermal or biological waste treatment as pre- or post-processing units. The mechanical treatment focused on selecting recyclables waste is introduced in so called material recovery facility (MRF).

- Thermal treatment. It involves incineration, gasification and pyrolysis. Incineration is combustion with excess of air guarantying high yields of organic carbon to carbon dioxide conversion. Gasification is a high-temperature process with external heating of the waste and low stechiometric (minor than one) of oxygen, resulting in the release of reduced gasses with high calorific value, while pyrolysis is partial oxidation (absence of oxygen) that increases the temperature subsequently resulting in the generation of pyrolysis gas and other sub-products. Thermal processes produce off gases and products that must be treated and cleaned.

- Biological treatment. It involves composting, anaerobic digestion (AD) and their combination. Composting is a biological aerobic process converting the putrescible organic waste into carbon dioxide and stable organic matter. AD is the degradation of organic waste in the absence of oxygen. This leads to methane and carbon dioxide production. The off-gases both from composting and AD must be controlled.

**Mechanical selection and Recycling**

Mechanical treatment is associated to type of waste and the desired output. The physical characteristics of the waste could be particle size, shape, density and flexibility, as well as ash and moisture content. Mechanical treatment can be categorized into size reduction, separation and compaction (increasing bulk density) [6].

Recycling is mainly a mechanical process that allows separating the waste and processing it for obtaining secondary raw materials (SRM). Presorting and separation technologies are essential for mechanical recycling. In case of mixed waste, sorting can be implemented manually or by mechanical selection in MRF. These treatment plants can be implemented for select waste from source separation or mixed waste, in order to obtain secondary products. The selection can be composed of [3]:

- Manual sorting. It is the technique mostly used in the world, as preliminary step for removing the heavy waste or maximizing the selection procedure.

- Drum screens. They are usually implemented for selecting the waste in function of the size of the material. The waste is fed into rotating drums where smaller materials drops though the hols of the trommel (under sieve) and the larger material will remain in the drum (upper sieve).

- Air classification. Separation of heavy and light waste based on material density using air flows.

- Magnetic and eddy current separators. Ferrous metals are separated from non-magnetic metals, which are then classified by the ’eddy current’, exposing the metals to a changing magnetic field.

- Near infrared sensors (NIR) and X-ray technology. X-ray allows assessing the type of waste based on their density (i.e. detection of PVC), while NIR sensors can distinguish the material between the different way that they have for reflecting the light.

- Milling. It allows producing small particles at the end of the process, in order to generate SRM

Therefore, mechanical treatment of waste is often used for the recovery of valuable materials, also in association with biological or thermal treatment processes.

### Treatment of organic waste: Composting and AD

**Composting** is an aerobic treatment of heterogeneous organic matters [6]. The process releases energy, part of it (about 50–60 %) used by microorganisms and the other is lost as heat. The first phase of the composting process is mesophilic, starting the aerobic decomposition of easily degradable organic matter. Within a few days, the thermophilic phase start, where the temperature can exceed 70°C. The positive effect of operating at high temperature is the reduction of pathogenic agents present in the waste. In composting plants, this phase is limited in terms of temperature and exposure time in order to obtain a balance between high stabilization rates and good sanitization. The third phase is the maturation, which includes the mineralization of slowly degradable fractions and the humification of lignocellulosic compounds. This phase can last some weeks, according to the composition of the starting material. Totally, the process takes about 11-12 weeks. The composting process leads to the production of $CO_2$, moisture, minerals and the biologically stabilized organic matter, called compost.

From a microbiological point of view, composting is a discontinuous process resulting from a sequential development of different microbial communities. To be called compost, the organic matter must be biologically stabilized, degraded into fine particles, and it should be a stable product that can be stored without further treatment. If stabilization has not been achieved, phytotoxins are produced in the soil. Stabilized compost should be divided by mature compost, since stabilized compost is the condition of the material after it has passed through the fist stage, while mature compost refers to compost that was stored for allowing the humification phase.

**AD** is defined as a biological conversion without oxygen, nitrate and sulfate. The final catabolic products are the $CO_2$ and $CH_4$. Different reactions within AD are mediated by different groups of microorganisms. This is why anaerobic digestion is often termed a structured and complex process. The different digestion processes are generalized in (1) Hydrolysis, (2) Fermentation (acidogenesis), (3) Acetogenesis, and (4) Methanogenesis. Fermentative organisms convert simple sugars and proteins to organic acids, alcohols, hydrogen, and carbon dioxide, and produce specific enzymes that hydrolyze complex particulates. Acetogenic organisms produce acetate from organic acids (fermentation), and waste electrons as hydrogen. This hydrogen and acetic acid are converted to methane by hydrogenotrophic methanogens and aceticlastic methanogens.

The main components in the biogas, $CO_2$ and $CH_4$, are determined by the composition of the waste digested. Fats produce a biogas high in methane, while carbohydrates produce biogas with equal amounts of carbon dioxide and methane. The biogas from anaerobic digestion of waste usually contains 55–65% $CH_4$ and 35–45% $CO_2$. Ammonia, $H_2S$ and numerous volatile organic compounds (VOC) usually constitute only less than 1% of the biogas.

The energy content in biogas usually exceeds the amount of energy used technically in running the anaerobic digester. The biogas can be used directly for producing electricity and heat or can be converted to a fuel, making the digester a net energy producer. In order to retrieve residual biogas production, methane is usually captured by flares or covering it after-storage tanks, in order to reduce environmental impacts.

The residue from AD can be a solid or a liquid effluent, if the process is wet. In the latter case the process runs in a mixed suspension of 4-10% total solids. As the digestion proceeds, the solid content decreases. The composition of the digestate depends strongly on the composition of the waste treated as well as the uses or disposal of the digestate. It can be use on land as a fertilizer (if based on digestion of biowaste), landfilled, incinerated or composted.

**Pre-treatment before landfilling and WtE**

Mechanical processing can take place before bio-degradation or final disposal in order to separate refuse derived fuel (RDF) or solid recovered fuel (SRF) and recyclables from the remaining waste [6]. The MBT plants can be divided in two cathegories: MBT for RDF production (bio-drying) and MBT for organic matter stabilization.

The first technology aims to convert the biodegradable carbon in RDF fraction. The first step is biological treatment, while the second step is mechanical treatment. All the waste is subject to a fast biological process acting as a drying process. Afterwards, metals are recovered and the inert fractions are removed and disposed. Finally, the main part of the waste ends up in the RDF/SRF fraction. Biological processing generates heat to evaporate a significant fraction of moisture in the waste, increasing the heating value. The target water content for the waste after stabilization is typically below 15% allowing a more efficient sorting of metals. The biological process step involves bio-drying for 5-7 days in container compositing systems. Magnetic iron scrap and eventually aluminum are recovered for recycling.

In the second technology, mechanical pre-treatment is the basic operations for material flow separation, shredding, sieving and magnetic separation. After size reduction, the waste stream is usually divided by use of drum screens into oversize and undersize flows. Both flows undergo magnetic separation for ferrous metals recovery. Typical screen sizes are 80mm. Biological processing can be aerobic treatment or anaerobic treatment. In MBT plants using composting for biological degradation, the process often takes place in two steps: intensive composting in windrows, containers or boxes for 4-5 weeks, and post-processing in roofed windrows for 9-10 weeks, varying from plant to plant and depending on process intensity and controls. AD for biological treatment are wet or dry fermentation processes with retention times of typically 3-4 weeks.

Therefore, MBT can be implemented as pre-treatment for reducing the environmental impacts due to final disposal, treating unsorted solid waste. Morevoer, MBT can increase the useful life of the final disposal site, reducing the amount of waste inflow and preventing organic fraction degradation and reducing the environmental impacts due to leachate and landfill gas emissions.

**Thermal treatment**

Waste incineration plants can treat waste of various compositions. It is the first main difference between waste incineration and other combustion systems (pyrolysis and gasification), and it has large implications on the design of the incineration plant. For the design of a waste incineration plant, data on the amount and composition of each waste type is needed, and the effect of expected future changes in the waste management system should be taken into consideration, for example the introduction of source segregation or pre-treatment [6].

In the incineration process the combustible components react with the oxygen of the combustion air, releasing hot combustion gas. The moisture content of the waste evaporates in the initial stage of the incineration process, and the non-volatile solids are converted in bottom ash and fly ash.

The combustion gases pass from the furnace to the after-burning chamber. It is required that the temperature of 850°C or 1100°C is maintained for two seconds in order to guarantee the avoidance of volatile organic compounds (VOC) generation. Furthermore, the waste cannot be fed into the incinerator before the required temperature is reached. Air emissions of CO and total organic carbon (TOC) are relate to the quality of the combustion process. Too low temperature of the process, lack of oxygen or too short flue gas residence time at high temperature causes the increas on CO and/or TOC generation, as well as other VOC.

The flue gas is cooled through the walls, the heating surfaces of the furnace and the boiler. In the boiler, pressurized water is heated and evaporated. The purpose is to exploit its energy in a steam turbine, which is connected to a power generator. In a combined heat and power (CHP) plant, typically 25% of the steam's energy content is transformed into electrical energy. The remaining energy is used in a heat exchanger, generating hot water for district heating purposes. Typical power generation efficiency would be 20–25% of thermal input for a CHP waste to energy plant, increasing to 25–35% in the case of power production.

**Gasification** is a thermal conversion of waste (carbon based) into high calorific outputs by partial oxidation with a gasification agent (air, oxygen or steam). Temperatures are in the range 800-1100°C and the process involved endothermal reactions, requiring heat which may be supplied by steam as gasification agent. The products from gasification are synthesis gas (syngas), with heating value around $3-12\,MJNm^{-3}$ that is 30–60% by weight of the input, tar and oil, around 10–20% by weight of the input, and solid, mainly ashes containing nonvolatile metals and other inorganic components that is around 30–50% by weight of the input.

Gasification products are highly affected by the waste input, temperatures, and process configurations. In particular the waste input is often consists of specific industrial fractions rather than mixed MSW. The composition of the produced gas greatly depends on the gasification agent used. Air gasification, for example, is cheaper than using pure oxygen as gasification agent, but results in a gas containing up to about 60% nitrogen.

**Pyrolysis** is the thermal degradation of organic material in the absence of oxidizing agents. Temperatures are typically around 300-800°C and the process is endothermal. Heat is often supplied indirectly through the walls of the reactor but compaction of the waste and friction may also contribute to heating the waste.

The composition and energy contents of the products depend on the waste input. As the gasification process, the main products are syngas, pyrolitic oils and tar. The syngas is a mixture of H2, $CH_4$, CO, $CO_2$, as well as other volatile constituents from the waste. The syngas yield can be around 20-50% by weight of the input. The heating value is around 3-12 $MJ\,Nm^{-3}$. The liquid produced is a mixture of tar, oil, and water containing a complex range of hydrocarbons (organic acids, phenols, PAHs and alcohols). The amount of liquid may be around 30–50% by weight with heating values around 5-15 $MJ\,kg^{-1}$. Finally, the solid phase is a char-like material containing the remaining solid products. The char, in the order of 20-50% by weight, may have a considerable ash content of 10-50%. The heating value of the char may be up to 10–35 $MJ\,kg^{-1}$.

Higher quality waste plastics and rubber (e.g. waste tires) may facilitate higher ratios of oils and gases, while more mixed wastes may generate more char and solid (inorganic) residues. The water content of the waste input also affects the process conditions. In the pyrolysis process, the waste is dried and the moisture released by heating to about 100-120°C. After this phase, a series of complex reactions occur by which VOC are released.

**Sanitary landfill**

Open dumps are the main final disposal site for low-income countries. The disposal sites are clay and gravel pits filled with waste, including industrial and hazardous waste. As long as the dumps are small and local, the main impacts are smells, rodents and local fires. However, as urbanization developed, the dumps are even bigger and urban areas moved close to the disposal sites making nuisances and sanitary issues more persistent and widespread.

The controlled sanitary landfill is a final disposal site that limit the access to the site, organizing the disposal activities and covering of the waste with soil. Less contact with the waste is the main sanitary improvement. The leachate and landfill gas are collected and treated by liners, collection systems and treatment facilities. However, liners are not always impermeable, leachate collection systems may clog, and leachate is difficult and expensive to treat prior to discharge in water bodies. Leachate recirculation is in some cases has been introduced as a treatment option for leachate and an approach to enhance gas generation for its exploitation.

Landfill gas, composed of $CH_4$ and $CO_2$, is generated by the AD of organic waste. For reducing the environmental issues and occupational risks (explosions, fires, greenhouse gas emission, odours) and for exploiting the gas for energy recovery, top covers, gas wells, flares and engines are implemented. The amount of gas generated depends on the amount and composition of the organic content of the waste. The gas moves out of the waste by the pressure that it builds, influenced by the structure of the sanitary landfill. The majority of the gas is generated within the first 15-30 years after disposal, but landfill gas emission should be expected also after this period. Based on model predictions and laboratory experiments, it has been found that the gas issue is insignificant 100 years after disposal of the waste.

Landfill leachate is the second main issue of a sanitary landfill. It is generated by the infiltrating rain percolating through the waste and the leaching of contaminants. Topcovers, bottom liners, drainage systems, and treatment plants are part of the control system of the leachate, in order to reduce the risk of groundwater and surface water pollution. The rate of leachate generation depends on the net infiltration, the top cover and the area of the landfill. The geometry and the top cover design significantly determine how much and how fast the waste is leached. Leaching may continue long after 100 years, so the critical issue is the concentration or flux of the pollutants.

In recent years, quality requirements of the waste that should be landfilled for closing of the landfills have been introduce, in order to avoid environmental contamination and boosting waste recycling and recovery. Moreover, international campaigns has been implemented in order to close the dumpsite in low-income regions [7].

### 3.1.3 CE model

Many barriers still exist for developing the CE in developing countries, particularly due to low financial sustainability, presence of informal recycling activities and the lack of technological facilities [8, 9]. For these reasons, rise the need to develop a theoretical model that could be affordable for these specific areas of the world.

Any CE model cannot be equivalent for every context due to social, environmental, financial and political differences. Moreover, there are many discrepancies among SWM in big cities and small communities, since financial power, waste production, social habits and urban areas are extremely different and require specific insights.

A general description of a reliable CE model for big developing cities, for the management of MSW (hazardous and non-hazardous), is introduced within this section [1]. Such model is simply depicted in Figure 3.1 and it intends to highlight re-circulation and treatment solutions of waste materials through technical facilities and improved social behaviors.

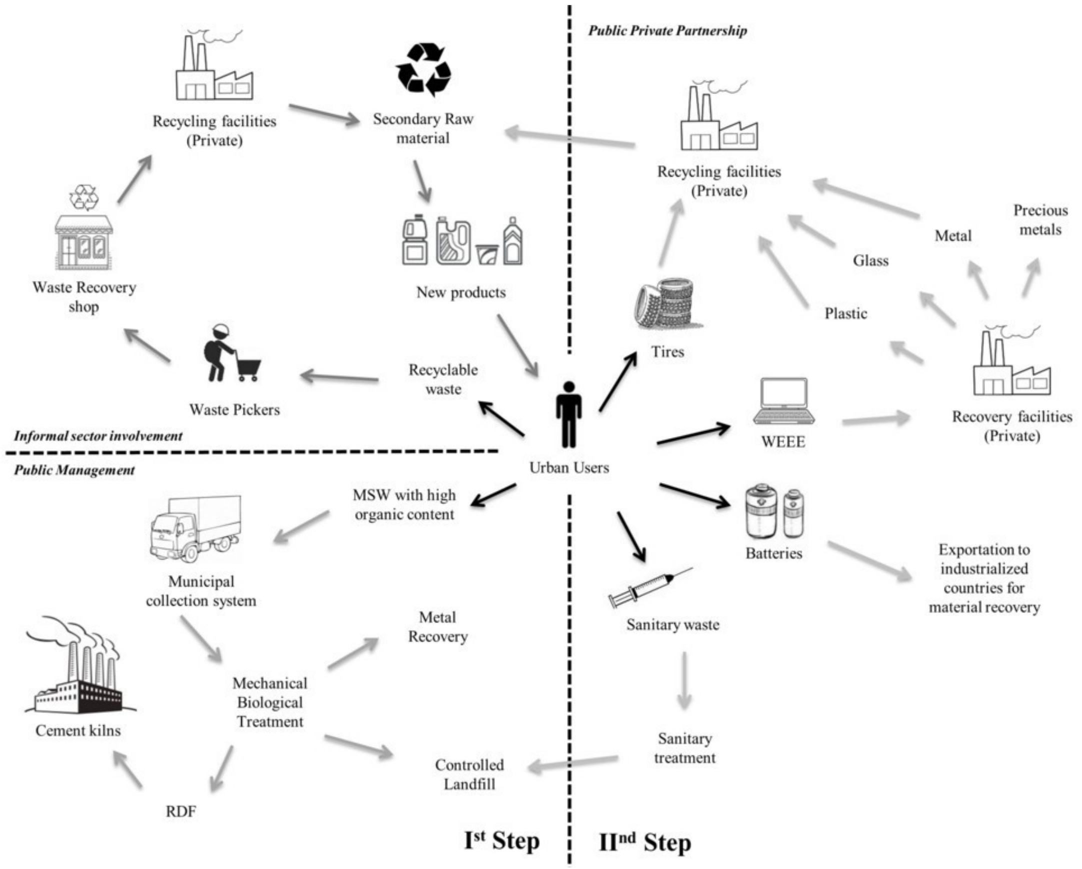


**Figure 3.1:** CE model for developing big cities [1]

However, other considerations should be introduced as regard small-scale communities or the recovery and treatment of the special waste. Considerations about these topics are avoided in this section. Attention is provided to recyclables, fractions with high organic content, and other urban waste such as used tires, sanitary waste, used batteries and waste electrical and electronic equipment (WEEE) (oils fractions are not assessed).

SC by municipal collection trucks is not considered, as too expensive to be applied in region with low GNI (<10,000 USD). For that purpose, the inclusion of the informal recycling sector is suggested as main solution for improving the SC system. Moreover, other precautions, appropriate in a low-income region, are recommended. All such considerations are divided in three groups, each supported by three different actors: informal recycling sector, public management and public-private partnership (PPP). Moreover, the CE is divided in two phases, in function of the times required for the application and for the urgency of its implementation.

**Formalization of the waste pickers**

The first issue is the formalization of the waste pickers. The informal trade implemented at municipal level is commonly an issue since the municipal perception of those who work in the informal recycling sector is often negative and in some instances, the relationship is hostile [10]. However, the informal sector provides the major source of recycling and save municipal money through reducing the quantities of waste collected for MSW treatment and disposal [10, 11, 12]. So, the introduction of a CE, which comprehend the presence of informal waste pickers, become of utmost importance. Taking into account global examples, scavengers usually work commonly into final disposal sites or picking waste from road bins, street containers, and riverbanks [13, 14]. However, they are responsible of a large part of recycling activities, starting recycling plans (RP) without the contribution of public financing. Therefore, efforts should be focused on supporting those countries in developing the strategies that incorporate waste pickers into the formal waste management process.

Therefore, the first step suggested in the model is the formalization of these workers, giving duties and rights, which can support the work. Public awareness should be improved by the introduction of advertising and sensitivity campaigns in order to introduce the "ecological operators" (name that should be given to the waste pickers) into the collection system. The municipality could guarantee sanitary assistance free and retirement at the end of their job career. Such aid should be assured by the introduction of the "zero tax" principle within the recycling chain, as the demand of charges represent a real barrier for the operators that are not encouraged to enter into the formal system. This device introduces also a reliable information system about the amounts of recyclable materials that commonly face with miscalculations since the waste picker is not encouraged to provide the real amounts.

At the same time, the ecological operator should accept to be formalized within a waste recovery shop and to work within a limited district area, recollecting the waste, user by user. In this manner, the citizens of each county will know every picker. For that purpose, municipal control and monitoring system are essential while the Government, to guarantee the same business for each shop and operator, should ensure market costs for waste recyclable materials. Finally, every worker should wear personal protective equipment (PPE), which could be provided by the municipality after the sign in into the recycling shops, in order to encourage the start of the process. This decision depends by local budget and willingness to participate of the pickers, main problem and challenge which should be addressed and considered.

**Formal MSW collection and pre-treatment before landfilling**

The formalization of the informal sector should be supported by a pre-treatment system before landfill, since the organic matter grow in percentage as well as the inorganic exploitable matter decrease. Commonly, MSW is sent to open dumpsites that are dangerous for the environment. Moreover, environmental reclamation is too expensive, and it is not affordable for a low-income country, worsening contamination extent. For that purpose, a MBT can be implemented before the final disposal site. It can guarantee organic waste stabilization and refuse derived fuel (RDF) production, converting waste-to-energy as fuel, addressing the issue of energy demand and SWM in a CE perspective [15].

Such highly energetic material is exploitable in industrial factories (i.e. cement kilns), as used in other developing areas [16]. In this manner, other economic revenues are guaranteed, and the final disposal site can be managed in a more sustainable framework since landfill gas production, leachate releases and unpleasant odors are reduced [17, 18]. Moreover, disposal site useful life is improved, enhancing environmental protection. MBT can be adopted in developing countries since it is a cost-effective treatment and it improves the environmental condition in emergency circumstances [19]. Moreover, the mechanical treatment applied could be introduced for the selection of recyclable materials, or could be applied manually, in order to boost the creation of new jobs.

Nevertheless, the model here suggested foreseeing the implementation of a controlled landfill, monitored and gated, so that no illegal activities can be introduced in the area and a control flux system can be adopted. The application of this step should be provided by the public management system and the main barrier consist in the lack of financial sustainability.

#### Second phase: SC and treatment of other solid waste typologies

The second phase of the CE model included the implementation of a more efficient SC applied by the citizens. In this case, SC cannot consider the inclusion of the informal sector since materials as tires, sanitary waste and batteries are generally not exploitable directly since economic revenues are not available, the treatment is unsafe, the transportation is uncomfortable, and the exploitation is not always introduced at local level. WEEE could be also recollected by the informal sector [20], however, this practice is dangerous for the environment and the population, since the WEEE contains hazardous materials and the informal selection is made with any precaution [21, 22, 23].

No specifications are provided in the model as regard the treatment methodology since many technologies are available for treating these waste fractions. However, WEEE and tires recovery is suggested, sanitary waste need to be treated for healthy precautions while batteries could be exported to developed countries that just adopted the recovery of these materials. Therefore, public economic efforts should be introduced in this step, which could be apply after the improvement and implementation of the objectives of the first phase, since public behavior started to accept a CE system with consciousness and perseverance in material selection.

Theoretically, these two phases should be introduced in parallel in order to introduce an effective CE; however, two steps were introduced since, typically, in developing countries a formal recovery and recycling system is not still in action, so the primary practice to take into account is the improvement of the landfill and the inclusion of the local activities. In this framework, a PPP can be applied since collection, treatment and exploitation strategies require an important effort that can be overcome only by the cooperation between public organization and private financing.

### Stakeholders involved in the CE system

The system can be sustainable for households, private sector and municipality: main advantages and disadvantages are reported in Table 3.1.

| Waste pickers | Municipality | Private sector | Households |
|---|---|---|---|
| **Advantages** | | | |
| (A1) Sanitary insurance for free and covering of the scholar expenses for the children. | (A1) Improvement of public sensitivity in SWM practices and inclusion of the citizens on the recycling practices. | (A1) Recycling activities enhanced by the collection of more recycling materials. | (A1) Curbside collection for free and organized, with no request of charges. |
| (A2) Organization with other operators, public acceptation and inclusion with the society. | (A2) Reliable information about recycling activities with reliable data for planning future improvements. | (A2) New markets introduced within the area, with the collaboration of the municipality for spreading the public awareness | (A2) Upgrading of street cleanness with the improvement of the sanitary state of the area surrounding the district. |
| (A3) Work recognized by the municipality with retirement guaranteed. | (A3) Sustainable management of Landfills, economic save and reduction of environmental impacts. | | |
| | (A4) Improvement of the recycling rate. | | |
| **Disadvantages** | | | |
| (D1) Introduction of a regulation within the daily collection activity. | (D1) Preliminary investments are required, while a new management system should be introduced. | (D1) Competition with new recycling companies which could be introduced thank to the high availability of recycling material. | (D1) Efforts required to change the usual MSW delivering. |
| (D2) Change in habits. | (D2) New policies should be introduced, also at national level. | | (D2) Accepting the activities provided by the 'informal sector'. |
| (D3) Collection areas limited and designated by the municipality. | (D3) Long time is necessary in order to introduce a visible change. | | (D3) Provision of the material in a selected manner. |

**Table 3.1:** Advantages and disadvantages for each stakeholder involved within the first step of the CE model [1].

Households can access to a curbside collection system without economic efforts and such SC guarantees clean neighborhoods. To boost the population to apply such methods, a municipal competition system can be introduced. For instance, the most "green district", that is the one which recycle the most per inhabitant, receive an economic discount in the sanitary charges or can be rewarded by public acknowledgments.

The private sector is also involved since more recyclable materials entered in the system without any financial improvement. The public sector reduces the costs of transports and final disposal since the expenses are commonly applied per ton of waste collected: so, the effort adopted to improve the informal sector is paid by the economic save enhancing environmental sustainability and public consensus. In addition, the inclusion of the national Government and the NGOs is assumed, although they are not considered as main actors involved but as stakeholders which are included into the system for achieving a sustainable management, as suggested by other authors [24].

The same collection model can be adopted also for private companies and offices that produce high amounts of waste that can be collected by the informal sector. However, public facilities like schools, nurseries and universities could sell or deliver the recyclable waste directly to the recycling shops or to the municipality like parallel public campaign in order to involve students and higher educational institute to develop a CE plan. Furthermore, the income derived or saved thanks to the activity can be used for improving the public structure, for introducing other sensitivity activities or for buying new bins and objects useful for improving the recycling rate, even made by recyclable materials. Moreover, organic waste from agriculture, markets and green areas can be deviated to a SC system, which is implemented periodically for introducing composting facilities. These applications should be introduced in pilot scale and could be considered as the third step that could be applied for improving the CE and reducing environmental impacts.

**The theoretical optimum framework: the third (final?) step**

The theoretical framework that should be achieved for improving CE in SWM is depicted in Figure 3.2. It involves three schematic parts of a MSWM system: SC and recycling of recyclable waste; collection, pre-treatment and final disposal of mixed waste; and SC and treatment of OFMSW. This model is mainly implemented in high-income countries, where the financial sustainability, the advanced regulation system, the presence of a stable market and the availability of reliable technologies allow its implementation.

The SC of recyclable waste is implemented formally, with SSC, compactor trucks, MRF and recycling plants, generating second-hand products that can be reused by the users. This system is more or less efficient, in function of the area where it is implemented and of the SC system implemented. It is a expensive system, which does not involved the activity of waste pickers or informal recycling, due to the lack of its activity in the area or the legal framework that does not allow its activity.

The mixed waste is collected by compactor trucks and pre-treated before landfill, in order to stabilize the OFMSW still present in the mixed fraction and to recover the recyclable fraction did not recover by the SC system. The product is a secondary recovered fuel (SRF) or RDF used for thermal valorization in incineration plants or similar thermal treatment facilities. The light ash is then managed as hazardous waste and disposed of in specific sanitary landfills.

The OFMSW is selected by DtD systems or similar with high efficiency. The organic waste is then treated in AD plants that produce energy delivered to households and public facilities. The digestate produced is then composted for producing high quality compost, useful for soil reclamation and agriculture in change of chemical fertilizers. The rejects obtained by the mechanical selection before and after treatment are disposed of in sanitary landfills or recovered in thermal treatment plants.

This MSWM system is difficult to be implemented in low income countries due to the lack of technology, know how, regulation systems and economic sustainability. Moreover, it does not consider the implementation of local technologies or system available for recycling or recovery the MSW. However, it should be considered as the final step for the implementation of an integrated and sustainable SWM system, in order to increase the recycling rate (RR) and reduce environmental impacts.

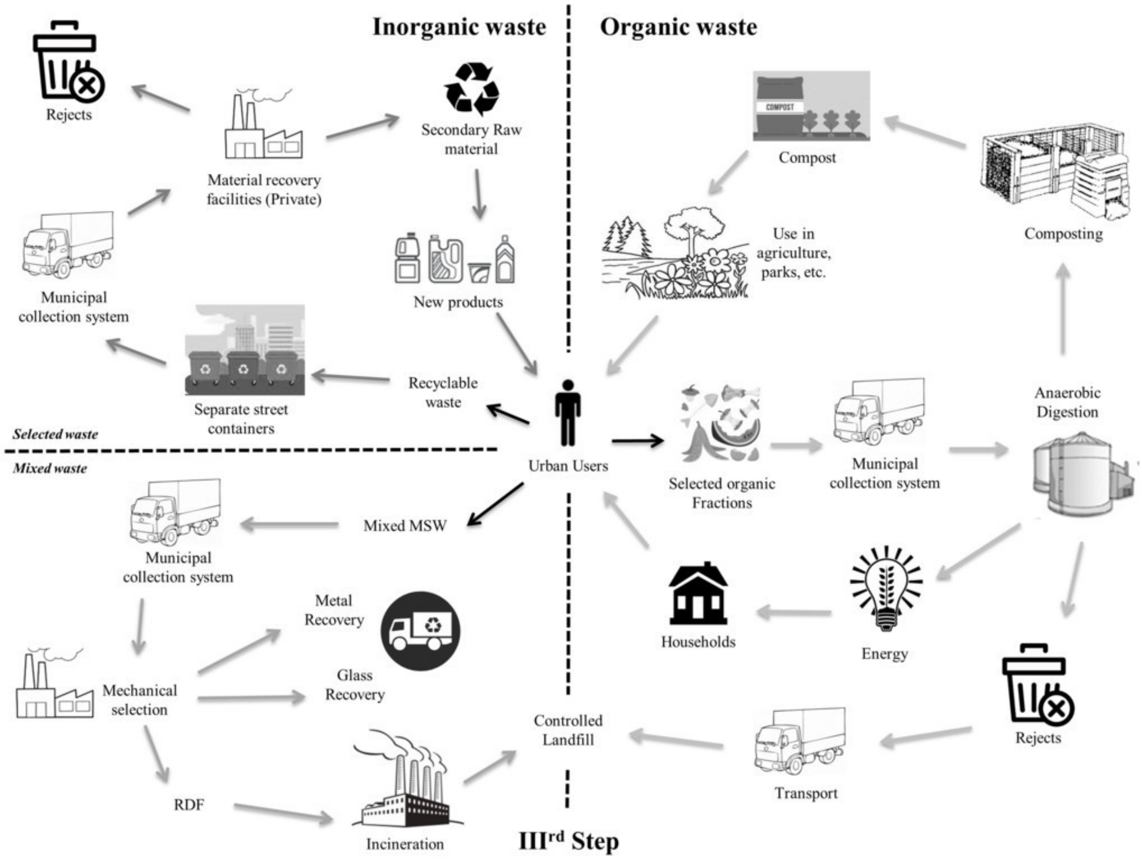


**Figure 3.2:** Ideal CE model, mainly implemented in developed countries: third step after the implementation of a step by step process.

## 3.2 MSW Management: Which scenario is suitable for improving the recycling rate?

This research refers to the article *"How to improve recycling rate in developing big cities: An integrated approach for assessing municipal solid waste collection and treatment scenarios" - Environmental Development* (Ferronato, N., Ragazzi, M., Portillo, M. A. G., Lizarazu, E. G. G., Viotti, P. and Torretta, V. - 2019).

### 3.2.1 Introduction

This study is driven by the need to develop a decision system for assessing the best MSW collection and treatment in La Paz. The objective is to spread the RR according to the requirements of the local Government and the national regulation introduced in 2016. For that purpose, six scenarios were introduced and assessed [25, 26] mainly in three steps:

- Applying a MCDA by a questionnaire submitted to local experts in the field of MSWM.
- Quantifying the material recovery rate, the GWP and the cost savings due to the reduction in transportation and final disposal.
- Comparing the questionnaire survey-MCDA with (1) the quantitative analysis of the impacts and (2) the ranking obtained, adding some considerations about the pros and cons of the procedure.

The MCDA was implemented specifically for discussing the typical multifactorial and multi-disciplinary issues concerning MSWM [27, 28]. In this research, the MCDA suggested by [29] was applied, due to its simplicity and suitability for cities in developing countries. In particular, this MCDA considered the opinion of various actors involved in the MSWM system and provided an indication about the topics that should be applied for improving MSWM sustainability. Therefore, Engineers' expert in the field of MSWM were interviewed by questionnaires. The answers were investigated, and a sensitivity analysis was applied in order to consider which scenario was the most relevant in function of each topic of the survey. Then, the scenarios were ranked in order to provide indication about the best scenario which should be implemented. Therefore, the structure of the MCDA used follows a basic model composed of: establishing the decision context, identifying the alternatives, defining the criteria for decision making and calculating the results by normalization process and sensitivity analysis [30].

For supporting the MCDA-questionnaire survey, the assessment of the GWP, material recovery and cost savings due to transportation and final disposal was implemented by quantitative data. The approach implemented is the same of a LCA [26, 31]. However, due to the lack of data and software support, the study was simplified. The data used for the quantitative impact assessment derived from the scientific literature, field analysis and the cooperation with the local stakeholders, such as NGOs, the local Government and Universities.

Finally, the results of the material, GWP, and economic impact were ranked together with the data obtained by the MCDA-questionnaire survey by the simple additive weighting method (SAW), for comparing the ranking found by the two procedures.

### 3.2.2 Management scenarios

Six future application scenarios are evaluated in function of its reliability in the context of La Paz. The collection and treatment systems introduced within section 3.1 were considered. The Bolivian regulation recommends the introduction of a SC system, with any other specification. For this reason, three SC methodologies were evaluated: DtD collection of OFMSW, SSC for recyclable waste, and formalization of the informal sector. Moreover, three treatment methodologies were assessed, since considered suited for La Paz due to its morphology, urban planning, climate conditions and current management options available at national level: MBT, composting, sorting and recycling of recyclable materials in MRF.

DtD collection of recyclable material was not considered while DtD of OFMSW was introduced only for assessing possible advantages in producing high quality compost. As regards treatment methodologies, WtE and AD were not considered feasible for the lack of specific studies on the calorific value of the solid waste, expertise and economic sustainability. Moreover, incineration is not still present in the country and no regulations are available concerning the production of RDF. Finally, AD in Bolivia is mainly applied in small-scale plant and mainly in small towns or rural areas, where the collection of OFMSW from markets and green areas is more feasible.

The collection and treatment methodologies were introduced in the scenarios in an integrated manner. For understanding the system boundaries, the scenarios are qualitatively presented in a flow chart, while some details are briefly described. The functional unit, the time of the intervention and the quantitative analysis are presented in the next section.

**Scenario 0** (S0) - Figure 3.3: landfilling. It is the MSWM current scenario: landfilling of the solid waste produced in La Paz, for a total of 550 t of MSW disposed per day. The recycling activities introduced by the informal sector and by the formal programs allows achieving about 8% of recycling rate, and such amount is considered within the study for assessing the current reduction of environmental impacts. To date, the collection system is mainly applied by street containers and compactor trucks, with no pre-treatment before landfilling.

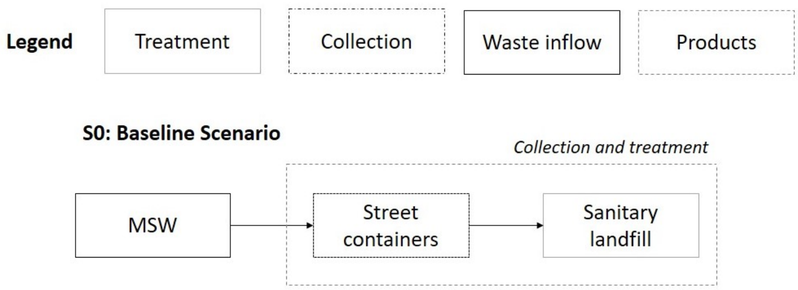


**Figure 3.3:** Scenario 0 of the MSW collection and treatment scenarios for La Paz [2]

**Scenario 1** (S1) - Figure 3.4: SC by SSC, composting and recycling facilities. This scenario considers the introduction of SSC for the SC of paper, plastic, glass, metal and the organic fraction. The introduction of selective and recycling facilities, for recyclable materials, and composting facilities for the stabilization of the organic fraction is suggested. The compost produced could not be considered of high quality and it could not be used as fertilizer, so it is recovered as landfill cover material.

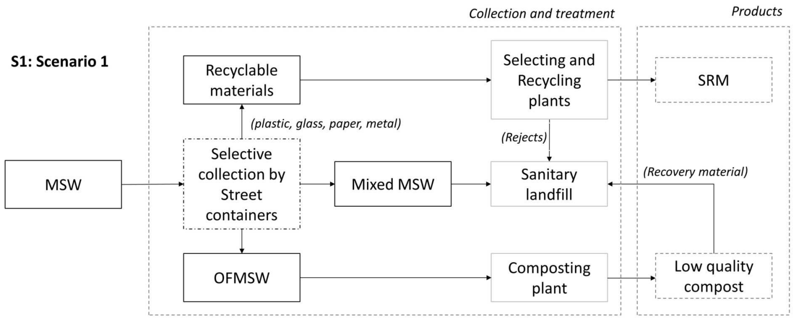


**Figure 3.4:** Scenario 1 of the MSW collection and treatment scenarios for La Paz [2]

**Scenario 2** (S2) - Figure 3.5: DtD collection of the OFMSW and mechanical selection of recyclable materials before landfilling. The second scenario considers the introduction of a system of DtD-SC of the organic waste, for reducing the quantities inflow into the landfill and for introducing a large-scale composting treatment. Moreover, a selection plant before landfilling is suggested, in order to select the plastic fraction available within the mixed material collected. The selection method could be manual, mechanical or both. The compost produced by the system could be used as fertilizer in the southern areas of the city, where agriculture is applied, and which could be treated by the implementation of a combination of pile turning and natural ventilation [32].

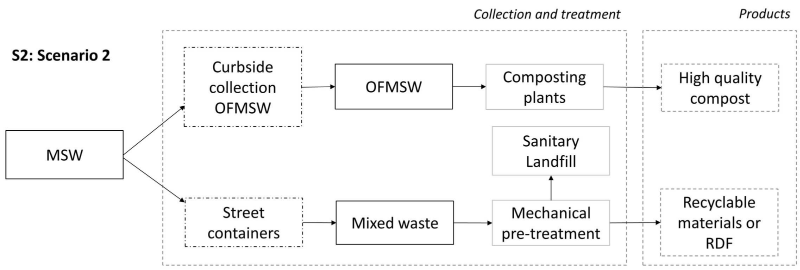


**Figure 3.5:** Scenario 2 of the MSW collection and treatment scenarios for La Paz [2]

**Scenario 3** (S3) - Figure 3.6: Inclusion of the informal sector and MBT before landfilling. This scenario plans to formalize the activity of the informal recycling sector, as mentioned in the national legislation (MMAyA2016.3) for the recovery of plastic, paper and metal. The aim of the scenario is to exploit the current recycling activity just applied in the city. The suggestion is to improve the collection made by this sector by the formalization in the regulation and by the diffusion of the system to the citizens, who should be sensitized. Moreover, the introduction of an MBT before landfilling is suggested, to reduce the impacts due to the organic fractions inflow into the landfill.

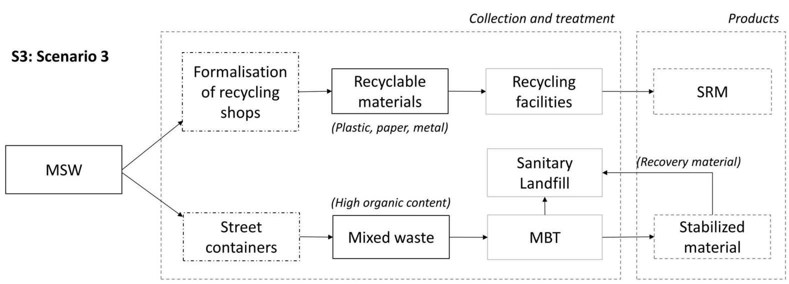


**Figure 3.6:** Scenario 3 of the MSW collection and treatment scenarios for La Paz [2]

**Scenario 4** (S4) - Figure 3.7: DtD SC of the OFMSW, treated by composting, and introduction of SSC of recyclable waste recovered in recycling facilities. The introduction of an OFMSW-SC and SSC (plastic, paper, glass) could allow the implementation of composting facilities and recycling plants. The aim is to improve considerably the RR of the city spreading the quality of the material recovered. Differently to S2, this scenario allows starting the collection of the recyclable materials at the source, with the introduction of facilities for the selection of each fraction. Moreover, it is an improvement of S1, where the collection of the OFMSW does not allow the production of good quality compost.

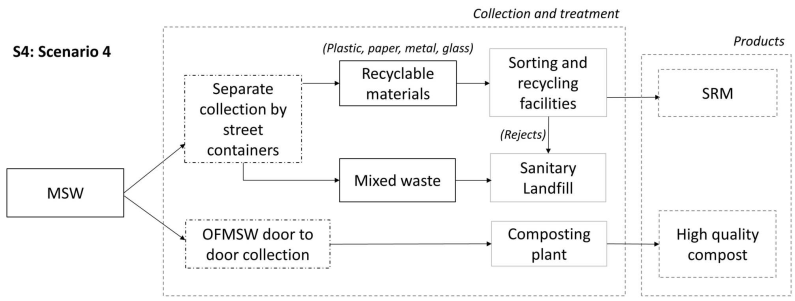


**Figure 3.7:** Scenario 4 of the MSW collection and treatment scenarios for La Paz [2]

**Scenario 5** (S5) - Figure 3.8: Inclusion of the informal recycling sector and introduction of DtD collection of the OFMSW, treated by composting plants. The aim of this scenario is to apply the SC of the recyclable materials by the formalization of the IS, as suggested in S3. The improvement consists of the introduction of a DtD-SC of the OFMSW, for introducing large-scale composting facilities and reducing the organic fraction inflow into the landfill. This is also proposed in S4 without the inclusion of the IS.

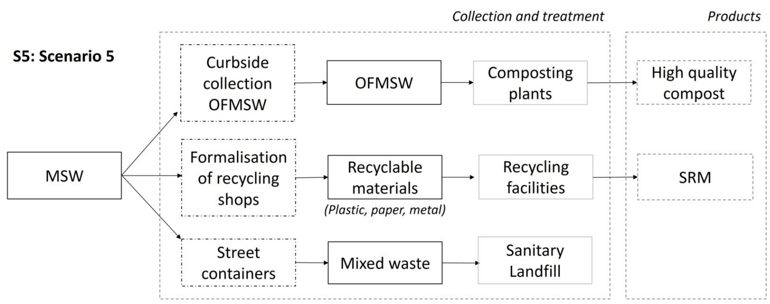


**Figure 3.8:** Scenario 5 of the MSW collection and treatment scenarios for La Paz [2]

**Scenario 6** (S6) - Figure 3.9 : SC of recyclable fractions by SSC and MBT before landfilling. The last scenario suggests the introduction of a SC of recyclable materials by SSC (plastic, glass, paper), as introduced in S1 and S4. For reducing the impact due to the OFMSW inflow into the landfill, an MBT is proposed, as mentioned in S3. This scenario should be considered to improve the collection of the recyclable materials and to apply the stabilization of the fraction with high percentage of OFMSW, which could be used as sanitary landfill covering material.

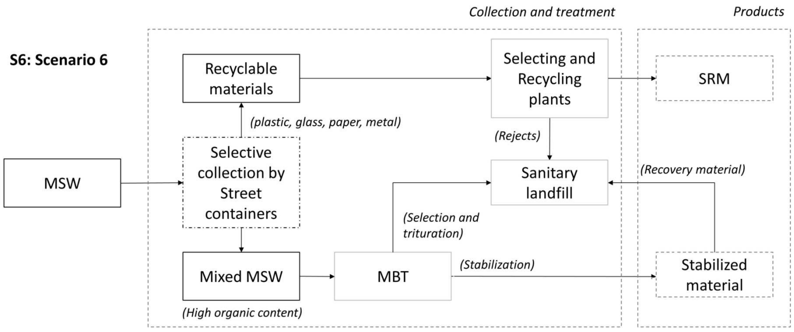


**Figure 3.9:** Scenario 6 of the MSW collection and treatment scenarios for La Paz [2]

### 3.2.3 Method - MCDA-questionnaire survey

#### Goal and Scope Definition

The objective of the MCDA is to provide indications about the possible scenarios for improving the RR of the city. Moreover, it introduces a discussion about the possible technological and management solutions for reducing environmental impacts, improving the local economy and the sustainable development of the city. The approach could be considered the first step before spending time, and money, for a technical study. For that purpose, the indicators and criteria assessed within the analysis were presented to local stakeholders by a questionnaire [29], in order to start a discussion about the topic and improving the awareness of local experts. The analysis considered the operation of the scenarios from its introduction to its application, along its useful life. Therefore, the answers provided consider this time boundaries.

#### Criteria and indicators

The MCDA contains five main indicators [29]: environmental prevention, economic feasibility, social inclusion, technological sustainability and management requirements. These indicators were considered satisfactory for covering all the aspects of a MSWM system. Moreover, the scenarios suggested, and the number of criteria, were measured for allowing answering the questionnaire in about 20 minutes. Each indicator set is characterized by different criteria, variable in number. Totally, the criteria considered within the study are 13. Details are provided below.

**1. Environmental protection**. The environmental protection of a project is an issue that should be assessed for improving the quality of water bodies, surrounding lands of the city and the local atmosphere. This indicator set has been divided in two criteria:

a) Reduction of environmental impacts (in terms of GWP), to evaluate which management option could be applied, in a framework of sustainable management and improvement of the environmental quality.

b) Recovery of the materials to produce SRM or compost, reducing the exploitation of primary resources. This criterion assessed how much material could be recovered by the SC and treatment system.

**2. Economic feasibility**. Economic feasibility is a central subject for low-middle income countries. It should be assessed carefully for considering the practicability of the project and for evaluating the best scenario. The main criteria assessed consider:

a) Operation and maintenance cost of the collection and treatment system. This criterion assessed the sustainability of the scenario suggested in terms of the expenses required for maintaining vehicles, containers and plants in the best management conditions. Thus, the cost increases in agreement with the complexity of the scenario.

b) Investment required for the application of the scenario. Often, it represents a barrier for developing future MSWM scenarios in low-middle income countries. The lack of financial sustainability was assessed in a qualitative manner by this MCDA as first indication about the cost of future management options. It considered the implementation of new treatment plants, vehicles, containers and bins.

**3. Social inclusion**. The inclusion of the population is compulsory to obtain the best result in terms of material selection and quality of the collection. This indicator set is the most complex, and is based on five different criteria:

a) Institutional support for the application of the management system. The support at municipal, regional and national level was assessed in terms of political will for applying a specific scenario. Such indication refers to the current will of the municipal administration, which could prefer a scenario among the others for economic interest, the social acceptance and the inclusion of the stakeholders, among other factors.

b) Creation of new jobs due to the new system applied. This criterion is introduced for considering the impact in terms of indirect economy: more families could be included in the recycling process, creating an indirect advantage of the financial balance.

c) The improvement of population health. In Bolivia, the main management activity for treating MSW is the final disposal in open dumpsites. It represents a real concern for citizens, so a future scenario should consider the improvement of the safety of the population, spreading environmental protection.

d) The awareness of the citizens about environmental concerns. It considers the improvement in social information, diffusion and circulation of the advantages about the application of the SC system. At the same time, the citizens should be aware of environmental and economic improvements as well as the reduction of health risks.

e) The inclusion of the community into the system. Sensitivity campaigns, seminars, student's involvement, among other activities, is considered within the scenario. Therefore, the main question is "does the scenario provide, or require, the conditions for introducing such activities?"

**4. Technological suitability**. In developing countries, the main management issue is represented by the technological feasibility and the expertise available in the area. Two criteria should be introduced within this set:

a) The feasibility of the introduction of the technology suggested. This mentions the application of the technological solution, which, in this case study, considers the application of MBT, recycling and selection facilities, large-scale composting facilities.

b) Technological adaptability and the flexibility of the scenarios with the context. This criterion takes more importance for the case of La Paz, where the geographical framework does not allow the introduction of every type of SC and facility.

**5. Management requirements**. The last indicator set included the evaluation of the presence of regulations and the time required for the application of the scenario. These factors are not negligible, since represent the starting point for the application of a new management plan:

a) The presence of regulations at national level. Specifically, for the case of Bolivia, where national regulations are under development, it could represent a barrier for introducing treatment technologies that are new to the country.

b) The time required for the full application of the system. The introduction of the system could require more or less time in function of its complexity. It depends on the application scale and change in behavior of the population.

**Questionnaire survey**

The answers of the questionnaire, for each criterion, were proposed in Likert scale, from 1 to 5, where 1 is the lowest score and 5 the highest. The questions, with its answers, are presented in Table 3.2. The questionnaire was filled up for each scenario.

At first, the questionnaire was submitted to a small group of environmental engineers, to correct possible misunderstandings and technical errors. Before its submission, the questionnaire was explained in all its structure, providing details of the criteria in terms of goal and scope of the analysis, the boundaries of the system, pros and cons of the methodology and technical options of the scenarios.

**Sample**

The questionnaire was provided to the participants by e-mail and in a working group organized by the University for discussing future MSWM plans. The working group and the e-mail were introduced with an enclosed explanation of the study and of each scenario, although without providing the results of the impact assessment. The participants were selected by a list of experts in the field of MSWM available at the University.

About 80 engineers were considered for the research, although only 35 answered the questionnaire, with an answer rate of 44%. The participants were all academics, authorities, engineers of NGOs, professionals of private companies and waste management professionals. In particular, the form was filled by 14 engineers of the private sector, 1 of the National Environmental Ministry, 7 of the public sector, 1 of the government of La Paz, 10 of the university as researchers or professors and 2 of local NGOs.

| Question sets and criteria | Answers in Likert scale (1 to 5) 1 | 5 |
|---|---|---|
| **1. Environmental protection** | | |
| Environmental impacts prevention | No, a little | Yes, a lot |
| Material recovery | No, a little | Yes, a lot |
| **2. Economic feasibility** | | |
| Organization and maintenance of the transport means and treatment facilities | Difficult | Easy |
| Investment required | It is not applicable | Feasible |
| **3. Social Inclusion** | | |
| Institutional support (at national, regional and municipal level) for the application of the system | Low support | High support |
| Creation of new jobs | Low | A lot |
| Improvement of the citizens health protection level | Low | A lot |
| Improvement of the awareness of the users | Low | A lot |
| Inclusion of the community within the process | Low | A lot |
| **4. Technological suitability** | | |
| Feasibility of the implementation of the technologies required | Low | High |
| Adaptability of the scenarios suggested | Low | High |
| **5. Management requirements** | | |
| Is there the national authorization for the application of the methodology? | No | Yes |
| Time required for introducing the system at an economic, social, technological and political point of view | >10 years | 1-2 years |

**Table 3.2:** Questionnaire survey for the MCDA [2].

### Data normalization, weighting distribution and sensitivity analysis

The total score obtainable for each scenario is $65$, and the first analysis consists on the evaluation of the scenarios that obtained the highest total score. Then, for evaluating the contribution of each question set, the answers were normalized by a linear function. Considering $\bar{y}^k_{i,j}$ as the average value of the criteria $i_{th}$ , of the indicator $j_{th}$, and of the scenario $k_{th}$, the value $Y^k_{tot,j}$ of the indicator $j_{th}$ and of the scenario $k_{th}$, is provided by equation (3.2.1):

$$Y^k_{tot,j} = \sum_{i=1}^{n^k_j} \bar{y}^k_{i,j} \ , \ k = (0, \dots, 6), \ j = (1, \dots, 5) \tag{3.2.1}$$

Where $n^k_j$ is the number of criteria of the scenario $k_{th}$ and of the indicator $j_{th}$. The normalized value is given by equation (3.2.2) and (3.2.3):

$$\tilde{Y}^k_{tot,j} = \frac{(Y^k_{tot,j})}{(max \ Y^k_{tot,j})} \tag{3.2.2}$$

$$maxY_{tot,j}^k = n_j^k \cdot max\ y_{i,j}^k \tag{3.2.3}$$

Where max$\bar{y}_{i,j}^k$ is the maximum value of $\bar{y}_{i,j}^k$ , equal to the highest score of the Likert scale. Introducing $w_j$ as the weight of the indicator $j_{th}$ and m the number of indicators used, the total value $V^k(w)$ for the scenario $k_{th}$ is given by equation (3.2.4):

$$\begin{cases} V^k(w) = \sum_{j=1}^m w_j \cdot \tilde{Y}_{tot,j}^k, \quad \text{m} = (1, ..., 5) \\ \sum_{j=1}^m w_j = 1 \end{cases} \tag{3.2.4}$$

At first, the weight $w_j$ of each question set is equal to $0.2$. Then, the indicators are assessed by a sensitivity analysis, for evaluating the opinion of the actors interviewed in function of the change of the indicators' weight. Each criterion assumes a weight from $0.1$, the lowest, to $0.9$, the highest.

### 3.2.4 Method - Impact assessment

**Functional unit, waste composition and system boundaries**

The functional unit used in the impact assessment refers to the quantity of waste daily and yearly collected. The total amount of MSW generated was estimated by the study introduced in Chapter 2, regarding the MSW generated in 2016 and is about 628 t per day, of which 31.4 t is not collected and 46.6 t is recycled both by the informal and formal sector. Therefore, in 2016, the total amount of waste inflow into the sanitary landfill was about 550 t per day. The fractions produced are composed of 12.8%wt. paper and cardboard, 2.6%wt. glass, 15.2%wt. recyclable plastic, 1.4%wt. metal, 47.3%wt. organic and 20.7%wt. inorganic non-recyclable [33].

The system boundaries of the scenarios introduced referred to the collection, transportation, treatment/exploitation and final disposal of the MSW. In particular, the MCDA considers the scenarios from its application to the results achievable, while the impact assessment considers the scenarios at their final stage, so when the SC and the treatment plants are completely implemented.

The study does not consider the operation and maintenance of the plants, neither the variation of the impacts during the years and the amortization of the investment costs. However, the approach considers the costs and the impacts per ton of waste finally disposed, recycled and treated. These simplifications were made for reducing in complexity the approach introduced, for allowing its simple applicability also in areas with low data availability.

**Material Recovery**

Commonly, the formal MSWM system applied in Latin America and the Caribbean does not consider the introduction of the SC of recyclable waste [34]. This is also explained by the low-middle income level of the countries, which is correlated with low recycling levels [35]. Differently, in high-income countries, the recycling rate is higher, and the formal SC system is well developed. An example is provided by the European Union, where the SC system is encouraged and supported by European regulations. For this reason, data about the SC by separate containers and DtD collection were gathered from the European high-income countries. The information were obtained from the EC [36], which provided a complete report about the recovery of recyclable materials in function of the collection system used. The best percentage obtained from the European cities were considered, to study the best scenario achievable by the collection methodology. It was assessed for plastic, metal, paper and cardboard, glass and organic waste.

The material recovery rate by MBT and the informal sector has been evaluated according to the scientific literature [37, 10]. In particular, [10] was reviewed for estimating an average RR obtained by the informal sector, considering mainly plastic, metal and paper recovery. Finally, the recovery rate of mechanical selection of mixed waste for obtaining plastic, metal and glass was introduced by [37].

The net material recovery rates obtained from the review of the scientific literature are reported in Table 3.3. The percentage obtained referred to the quantities of material recovered at the end of the selection and treatment system. Therefore, the quantities provided in the results section refer to the net amount of recyclable MSW recovered by the system, while the quantities remained are disposed to landfill.

| | Plastic | Paper | Metal | Glass | Organic | References |
|---|---|---|---|---|---|---|
| DtD | | | | | 70% [a] | [36] |
| SC | 25% [b] | 45% [b] | 35% [c] | 55% [d] | 3% [e] | [36] |
| Mechanical selection | 30% | | 60% | 13% | | [37] |
| Informal sector | 40% [f] | 15% | 40% | | | [10] |

[a] Lubiana
[b] Praga
[c] Tallin
[d] Lisboa
[e] Paris
[f] Average recovery rate

**Table 3.3:** Net material recovery rate for each typology of MSW collection [2].

### Economic analysis

The cost of the MSW transportation and final disposal have been considered for evaluating the cost savings introduced by each scenario in comparison with S0. Moreover, some considerations were added in function of the recyclable MSW sold.

**Waste collection**. Transport represents the most expensive management activity concerning MSWM in developing countries [38]. The current cost of MSW collection and transportation in La Paz is about $36\ USD\ t^{-1}$. This amount is considered within this study for evaluating the cost saved in case of reduction of waste transported due to the informal sector. It is assumed that the expense of the transportation is equal for each typology of SC system. The hypothesis is that the provider of the service does not change and the price that the municipality should pay remains the same.

**Final disposal**. The main MSW treatment applied in La Paz is the final disposal in sanitary landfill. As a result, the second economic expense regarding MSWM is the cost of MSW disposal. The cost considered in the evaluation is $14.5\ USD\ t^{-1}$ of waste inflow into the landfill. As the transportation cost, this represents the expense for the final disposal paid by the local municipality to the private sector that operates the landfill. The study assesses the cost savings of the local Government due to the reduction of MSW inflow into the landfill thank to the improvement of the RR. The recycling by the informal sector, the inclusion of sorting facilities and the reduction of the mass of waste by biological treatment are also considered in the study. Specifically, MBT of the OFMSW allows reducing 30% in mass of the waste [19].

**Market of the recyclable materials**.The particularity of the Bolivian case is that the private recycling sector pays the municipality for the quantities of recyclable materials provided. This represents a real advantage that could drive the public management to improve the current MSWM introducing recycling policies. This consideration is added within the economic analysis, since can provide the magnitude of the economic gain which could be exploited by the public sector. In evaluating these amounts, the cheaper cost of the recyclable material sold in the local market of La Paz was considered: about $150\, USD\, t^{-1}$ of paper, plastic and glass and about $450\, USD\, t^{-1}$ of metal. In this case, it was considered as a fixed price, although the fluctuation of the costs is influenced by the market and could vary during a year.

### GWP

The assessment of the GWP has been introduced by the evaluation of the emission due to MSW transportation and final disposal. Moreover, the recycling contribution in emission reduction is also considered. The impact evaluated is the GWP, expressed in $kgCO_2 - eq$, due to the emissions of methane and $CO_2$.

**GWP due to transportation**. The GWP due to MSW transportation was evaluated by real data. Emission of transportation trucks has been considered, as well as the quantities transported, and the kilometers traveled. On average, the compactor trucks, used by the collection system, emit $0.54\ kgCO_2\ km^{-1}$, transport a minimum of 5 t of waste, and travel 40 km. As a result, data obtained represents the kg of CO2 emitted per ton of waste transported, which is equal to $4.32\ kgCO_2\ t^{-1}$. This result is multiplied by the quantities of waste transported by the formal sector in daily and yearly basis.

**GWP due to final disposal**. The emissions due to the sanitary landfill, which affect the effect of GWP and climate change [39], are obtained from the scientific literature. The bio-gas produced per ton of fresh MSW inflow into the landfill range from $160$ to $240\ m^3\ t^{-1}$ [40].

In this study, the production of $200\ m^3\ t^{-1}$ of OFMSW inflow into the landfill has been considered, of which 59% is methane and 40% $CO_2$, while 1% are non-methanogenic compounds [41]. The quantity of methane has been increased by a factor 25 which represents its GWP [42]. Moreover, the densities of methane and $CO_2$ were considered of $0.667$ and $1.831\ kg\ m^{-3}$ respectively [41]. Therefore, the GHG emitted by one ton of OFMSW into the landfill is $78.7\ kgCH_4$ and $146.5\ kgCO_2$. For assessing the theoretical impact due to waste inflow into the landfill and its mismanagement, typical of developing countries [16, 43], the combustion of bio-gas by capture wells and combustion torch was not considered, so 100% of landfill bio-gas flow into the atmosphere.

Finally, the bio-gas emission due to waste stabilization has been introduced within the study. It has been estimated that the OFMSW stabilized by MBT reduced the production of bio-gas from $200$ to $57\ m^3\ t^{-1}$ of waste [19], which is equal to $22.4\ kgCH_4\ t^{-1}$ and $41.7\ kgCO_2\ t^{-1}$ of OFMSW.

**GWP reduction due to recycling**. The reduction of GHG emission has been evaluated. Data provided by [44] were used. The average emission avoided due to paper, glass, plastic and metal recycling are $-601\ kgCO_2 - eq\ t^{-1}$, $-417\ kgCO_2 - eq\ t^{-1}$, $-788\ kgCO_2 - eq\ t^{-1}$ and $-3789\ kgCO_2 - eq\ t^{-1}$ respectively. These emissions avoided are introduced in function of the MSW recycled by the system.

### Ranking of data obtained

Data obtained by the MCDA-questionnaire survey, the RR, GWP and economic analysis are finally analyzed for evaluating the best final scenario which could be introduced in La Paz. In particular, two comparisons were introduced:

- The comparison between the results obtained by the MCDA-questionnaire survey and the impact assessment.
- The comparison of the total ranking obtained by the MCDA and by the total ranking found with the combination of the two methods. The aim is to evaluate possible changes in the final ranking.

For the second point, a SAW method was introduced. The normalized score $X_j^k$ obtained for the impact $j_{th}$ of the scenario $k_{th}$ is calculated with equation (3.2.5).

$$X_j^k = 1 - \frac{(x_j^k - x_{(j,min)}^k)}{(x_{(j,max)}^k - x_{(j,min)}^k)} \tag{3.2.5}$$

Where $x_j^k$ is the value obtained for the impact $j_{th}$ of the scenario $k_{th}$, $x_{j,min}^k$ is the minimum value while $x_{j,max}^k$ is the maximum value obtained. The final score $W^k(w)$ of the scenario $k_{th}$ is given by equation (3.2.6).

$$\begin{cases} W^k(w) = \sum_{(j=1)}^{l} w_j \cdot X_j^k + \sum_{j=1}^{m} w_j \cdot \tilde{Y}_{(tot,j)}^k, \quad \text{l} = (1,\ldots,3),\ \text{m} = (1,\ldots,5) \\ \sum_{j=1}^{l+m} w_j = 1 \end{cases} \tag{3.2.6}$$

Where $l$ is the number of impacts assessed in the study. In this case, the weights $w_j$ were all used with the same value, equal to $0.125$, obtained by the sum of the weights divided by eight, equal to the sum of the indicators assessed by the questionnaire survey (five indicators) and the impacts of the quantitative analysis (three impacts). The use of equal weights was introduced in order to compare these results with the ones of the MCDA-questionnaire survey that was estimated with the weight $w_j$ equal to $0.2$, the same for the five indicators assessed within the questionnaire survey.

## 3.2.5 Results - MCDA-questionnaire survey

### Results of the survey and comparison among the scenarios

The results of the questionnaire survey allow obtaining an average consideration about the feasibility of the scenarios introduced, providing the point of view of local experts. The final scores obtained, normalized for each scenario, are reported in Table 3.4.

The final ranking is S4> S5> S2> S3> S6> S1. S4, S5 and S2 are the scenario that considered the application of the DtD-SC of the OFMSW, which represents the best solution suggested by the local stakeholders for improving the sustainability of the MSWM system. However, to date, there are not examples or pilot projects applied in the city at household level. The idea is to exploit the waste fraction most produced in the city, which is the organic one. Therefore, the implementation of the OFMSW-SC is considered mandatory for improving the MSWM system of the city. In parallel, the first methodology suggested for exploiting the recyclable material is the introduction of

SSC, while the second is the inclusion of the informal sector. The introduction of MBT, both for reducing environmental impacts and improving the recycling rate, is never considered useful for the city. The worst option is S1, with the SC of all materials by street containers. This is due to the low quality of the OFMSW that could not be used for composting.

| | Environmental protection | Economic feasibility | Social Inclusion | Technological suitability | Management requirements | Total | Ranking |
|---|---|---|---|---|---|---|---|
| S1 | 0.66 | 0.57 | 0.65 | 0.59 | 0.66 | 3.13 | $6^{th}$ |
| S2 | 0.78 | 0.57 | **0.78** | 0.65 | 0.65 | 3.42 | $4^{th}$ |
| S3 | 0.78 | **0.64** | 0.69 | **0.68** | 0.65 | 3.43 | $3^{rd}$ |
| S4 | 0.83 | 0.60 | 0.77 | 0.64 | 0.66 | **3.50** | $1^{st}$ |
| S5 | **0.84** | 0.61 | 0.75 | 0.61 | 0.66 | 3.48 | $2^{nd}$ |
| S6 | 0.80 | 0.53 | 0.69 | 0.62 | **0.69** | 3.33 | $5^{th}$ |

**Table 3.4:** Normalized score obtained for the MCDA-questionnaire survey. The highest score per indicator are reported in bold [2].

Analyzing each indicator, the rank change in terms of preferences. Considering the specific indicators, S4 is never the preferred solution. S2 wins on the social aspect, where the inclusion of the population, the creation of new jobs, and the requirement of public campaigns is considered more important than other scenarios. As regards environmental sustainability, the best scenario is S5, which considered the application of the OFMSW-SC and the formalization of the informal recycling sector.

S6 is considered the solution that could be applied faster and that could be supported by the local government. The application of an MBT and the introduction of street containers is considered faster mainly due to the low requirements in social cooperation. Finally, S3 was the best in terms of technological and economic sustainability. S3 suggests the introduction of the informal recycling sector for collecting recyclable materials while the mixed waste is collected by street containers and is pretreated by MBT. Therefore, the main economic and technological improvement is due to the introduction of an MBT.

#### Sensitivity analysis

The sensitivity analysis allows understanding if the result of the assessment changes in function of the different weight provided to the indicators. The total score obtained by the scenarios change in function of the importance provided for each indicator. In Figure 3.10 are reported the results about the economic and technological indicators.

By this analysis, it has been found that S3 is the most affordable for economic and technological sustainability, while, as concern environmental protection, S5 is the most appropriate. Both scenarios considered the inclusion of the informal sector which represent a win-win process, in which the municipality could save economic resources and reduce the waste dispose of to the landfill and the transportation.

The economic and technological variable could be considered the most important in the context of La Paz due to its lack of financial sustainability and know-how. In this sense, the application of S1 could not be considered suited for the city, as well as regarding social inclusion. Finally, S6, the application of the SSC of inorganic materials, the solution suggested by the local government, with the application of the MBT, could be considered the best scenario as regard management requirements. This is in accordance with the results reported in Table 3.4, where the weights were the same for each criterion.

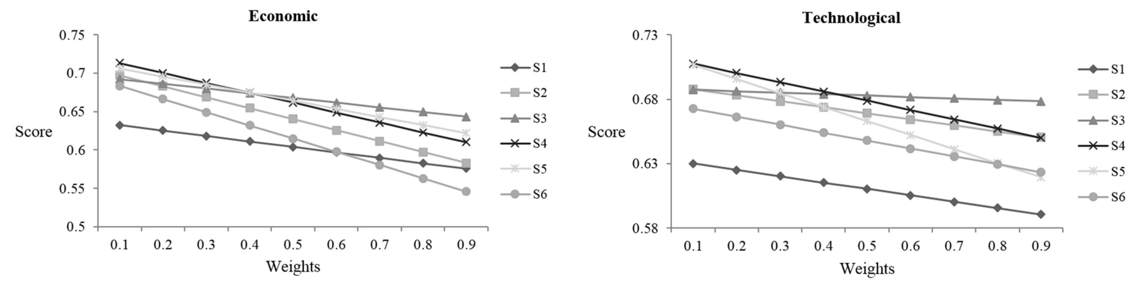


**Figure 3.10:** Sensitivity analysis of the scenarios about the technological and economic indicator.

The sensitivity analysis also highlights that the final ranking is a function of the weights provided for each indicator, and that there is not a unique solution for solving the MSWM requirements of the city. On balance, the main considerations provided by the sensitivity analysis are that a priority should be introduced for choosing the appropriate scenario, and that an integrated system should be applied within the city.

### 3.2.6 Results - Impact assessment

#### Comparison of the RR

The RR and the total amounts of MSW inflow into the landfill are reported in Figure 3.11. The highest RR could be achieved by the introduction of DtD collection of the OFMSW. .

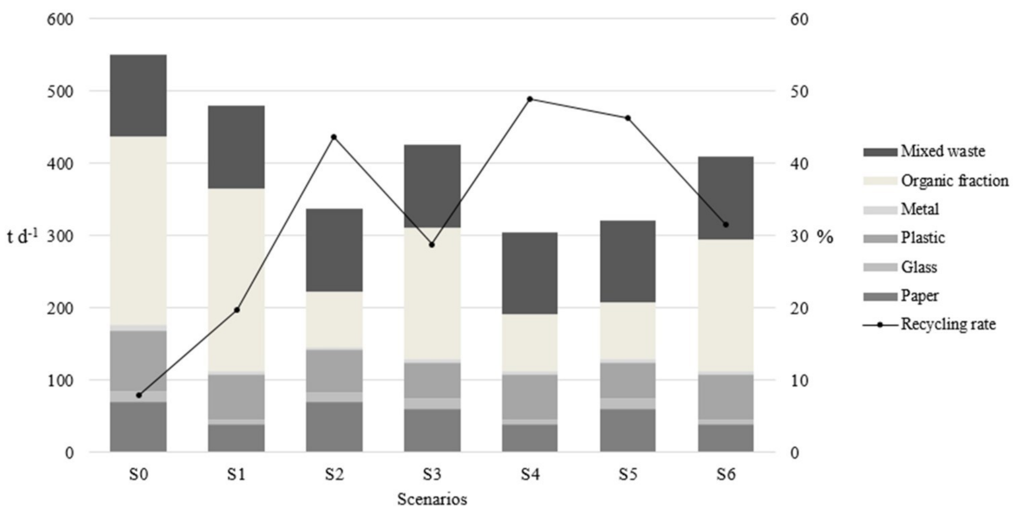


**Figure 3.11:** Waste inflow into the sanitary landfill and net recycling rate for the MSWM scenarios suggested [2].

As a result, S5 and S2, which considered the same methodology for collecting the OFMSW, allow recycling 46% and 43% of MSW. Results show that the maximum RR achievable is 49% of S4, by the introduction of separate containers for recyclable materials and the introduction of a DtD-SC of the OFMSW. The last scenario is S1, which achieved a RR equal to 19.7%. The low amounts of MSW recycled is due to the application of SSC, which do not allow the recovery of the OFMSW.

Comparing these results with S0, all scenarios are advantageous since allow improving the material recovery and the useful life of the sanitary landfill. In particular, evidence of the results suggested the introduction of an OFMSW-SC, for considerably reducing the MSW amounts inflow into the sanitary landfill since it is the highest fraction detectable

**Cost savings**

The cost of the MSWM system as regard transportation, final disposal and gain from the commerce of recyclable materials, as well as the net cost savings of each scenario, are reported in Figure 3.12. The scenario that allows saving the most is S5, with more than 2,600,000 USD reduced per year. This is allowed by the inclusion of the informal sector into the system, since its activity is not an expense of the municipality, so it represents an effective saving. This is also evident by S3, where the formalization of the informal sector is again suggested, since it allows saving about 2,200,000 USD per year. Moreover, the SC of the OFMSW allows reducing the costs due to the effective reduction of MSW inflow into the sanitary landfill, as well as the implementation of an MBT.

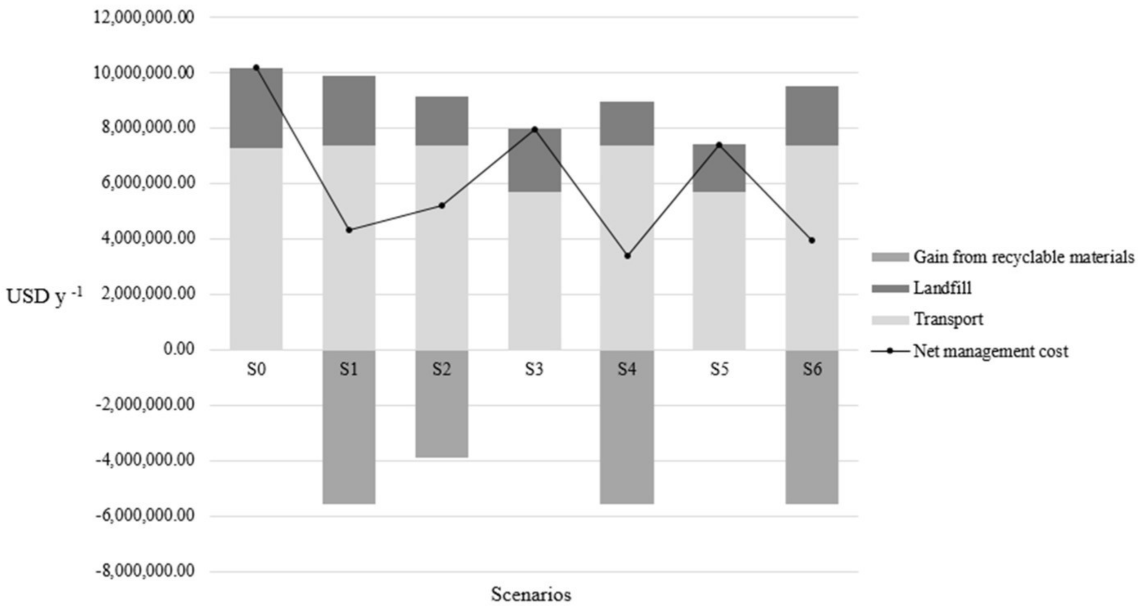


**Figure 3.12:** Transportation and final disposal cost of the MSWM system. The negative value represents the income due to the commercialization of recyclable materials [2].

This comparison suggests how the introduction of other methodologies means the reduction of the expenses, which could be used for the investment in other strategies, such as MBT, recycling campaigns and the introduction of SSC. Moreover, considering the recycling of plastic, glass, metal and paper the financial balance increase in sustainability. Considering the net expense value, the application of SC scenarios is evidently more interesting. S1, S2, S4 and S6, where the recycling chain is improved by the public MSWM system, allow saving about half of the total expenses of S0.

The introduction of new MSWM scenarios, different from S0, is suggested since the initial investments could be amortized by the reduction of waste inflow into the final disposal site, the reduction of the transportation costs and the sale of recyclable materials. In terms of net value, S4 is the scenario more affordable in this case, due to the possibility to sell high amounts of recyclable waste and to reduce the OFMSW to final disposal.

### GWP

In Figure 3.13 the results of the GWP, expressed in $tCO_2-eq$ per year, are reported. S0 contributes to the GWP with the emission of about $200,000$ $tCO_2-eq\ y^{-1}$. It could be estimated that about 90% of the GHG emissions of MSW collection and final disposal are due to the anaerobic digestion of the OFMSW inflow into the sanitary landfill. Within the analysis, the GHG emission net value is considered, which is the sum of the releases of the MSWM system and the emissions saved due to recycling. The contribution of recycling in GHG emission reduction was estimated by LCA [44, 45].

Comparing the net values, the most sustainable scenarios are S3 and S6, reducing about $176,000$ $tCO_2-eq\ y^{-1}$. The formalization of the informal sector allows improving recycling, reducing transportation impacts. Moreover, the introduction of an MBT reduces the impacts due to OFMSW degradation in sanitary landfill, while the mechanical selection of plastic improves the RR. The realization of an MBT plant can reduce considerably the GWP due to landfill mismanagement, and it is reported also by S6, where the net value of GHG emissions is considerably reduced. S1 represents the worst choice if compared with other scenarios since allows reducing only $23,000$ $tCO_2-eq\ y^{-1}$. The main issue is the reduction of the OFMSW. SC by SSC does not represent the best practice, although the selection of recyclable materials could be attractive for reducing the GWP.

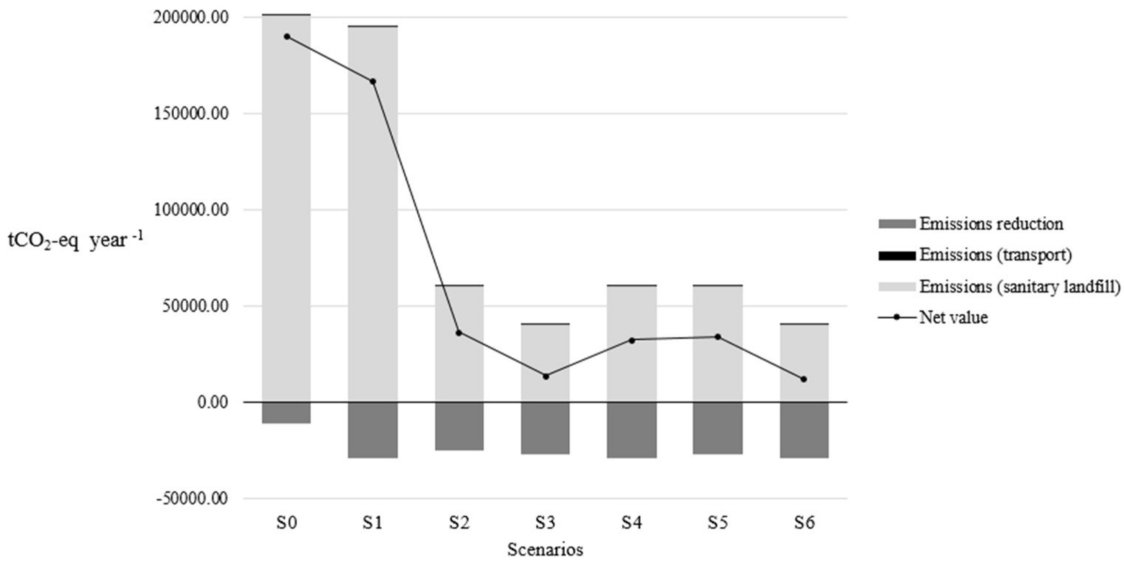


**Figure 3.13:** GWP of the MSWM scenarios [2].

### 3.2.7 Results - Integrated assessment of the scenarios

Table 3.5 reports the overall rankings obtained for each scenario with the MCDA-questionnaire survey and the quantitative approach. The rankings obtained by the MCDA-questionnaire survey represent the sum of the criteria for each indicator. However, for comparing the MCDA-questionnaire survey with the quantitative approach, the specific criteria that referred to the material recovery, cost savings and GWP should be considered. Therefore, criterion (b) of the first indicator (Environmental protection) is compared with the material recovery indicator assessed by the quantitative approach; criterion (a) of the first indicator (Environmental protection) is compared with the GWP indicator assessed by the quantitative approach; finally, criterion (a) of the second indicator (Economic feasibility) is compared with the cost savings indicator of the quantitative approach. The aim is to assess the accordance between the opinion of the local experts in SWM and the quantitative assessment introduced in the study.

| | MCDA - questionnaire survey | | | | | Impacts assessment | | |
|---|---|---|---|---|---|---|---|---|
| n. | Environmental protection | Economic feasibility | Social Inclusion | Technological suitability | Management requirements | Material recovery | Cost savings | GWP |
| $1^{st}$ | S5 | S3 | S2 | S3 | S6 | S4 | S5 | S3 |
| $2^{nd}$ | S4 | S5 | S4 | S2 | S4 | S5 | S3 | S6 |
| $3^{rd}$ | S6 | S4 | S5 | S4 | S5 | S2 | S4 | S4 |
| $4^{th}$ | S3 | S2 | S3 | S6 | S1 | S6 | S2 | S5 |
| $5^{th}$ | S2 | S1 | S6 | S5 | S3 | S3 | S6 | S2 |
| $6^{th}$ | S1 | S6 | S1 | S1 | S2 | S1 | S1 | S1 |

**Table 3.5:** Ranking of the scenarios suggested for each criterion assessed [2].

Concerning material recovery, the ranking obtained by criterion (b) of the MCDA-questionnaire survey is S5> S4> S3> S2> S6> S1, while the data obtained from the quantitative assessment, reported in Table 3.5, provided the ranking S4> S5> S2> S6> S3> S1. In both cases, the first two best scenarios are S4 and S5, which considered the introduction of OFMSW-SC, while the last is S1. As regard the reduction of environmental impacts, expressed in GWP, the ranking obtained by criterion (a) of the first indicator of the MCDA-questionnaire survey suggested S4> S5> S6> S2> S3> S1, while the quantitative approach provided S3> S6> S4> S5> S2> S1, again with S1 the last for both assessments, although with differences as regard the best scenario. In particular, the ranking of the quantitative approach is obtained comparing the GWP net value of each scenario (see Figure 3.13). Finally, comparing the operation and maintenance of the questionnaire survey - second indicator, criterion (a) - and the cost savings indicator of the quantitative approach (Table 3.5), can be highlighted that the ranking obtained by both methodologies is equal to S5> S3> S4 for the first three positions, so suggesting S5 as the most reasonable.

The final ranking provided by the MCDA-questionnaire survey, using the SAW method and considering the same weight for each indicator, was S4> S5> S3> S2> S6> S1 (Table 3.4). Normalizing and weighting the overall rankings obtained by the qualitative and quantitative methods, a final ranking could be obtained. For that purpose, the SAW method was introduced using the eight indicators of Table 3.5, implementing the same weight for each (equal to $0.125$), as explained in detail within the methods section. Results of the final ranking obtained combining the quantitative and qualitative approach are reported in Table 3.6. The final ranking is S5> S4> S3> S2> S6> S1 (Table 3.6), so always considering S1 as the worst and S4 and S5 the best scenarios for the city, if compared with the overall ranking of Table 3.4.

| | S1 | S2 | S3 | S4 | S5 | S6 |
|---|---|---|---|---|---|---|
| Total score | S1 | S2 | S3 | S4 | S5 | S6 |
| Final ranking | $6^{th}$ | $4^{th}$ | $3^{rd}$ | $2^{nd}$ | $1^{st}$ | $5^{th}$ |

**Table 3.6:** Ranking obtained combining the MCDA-questionnaire survey and the impact assessment [2].

This result, in parallel with the ones found comparing the specific criteria of the qualitative approach with the indicators of the quantitative approach, suggested that the opinion of the local stakeholders mostly agrees with the quantitative results, so local awareness can be considered of good level for the application of new management plans. Moreover, the combination of these methodologies provided an integrated assessment that allows considering the results suited for the local context, although environmental impact assessment should be better discussed with the local stakeholders and analyzed with more complex approaches.

### 3.2.8 Pros and cons of the methodology

This study considered the most feasible scenarios for the implementation of an integrated MSWM system for improving the RR in La Paz. Some hypothesis were made, considering that it is counterproductive for Bolivia the application of strategies developed for high-income countries, such as AD, RDF and incineration [46].

As suggested by other authors [47], the application of a MCDA should be supported by the application of an integrated assessment of qualitative and quantitative data, specifically for the case study where the research took place. Therefore, an integrated tool was provided, which considered both MCDA-questionnaire survey and impact assessment. In particular, since the considerations provided by the MCDA-questionnaire survey depend on the opinion of local engineers, a comparison with quantitative data was considered obligatory. Other MCDA were applied in other case studies of Latin America regarding solid waste management and renewable energy. [48] suggested the use of MCDA in Brazil and Latin America countries as a fundamental step for selecting a third-party reverse logistics provider. [49] applied a MCDA for assessing the best energy policy applicable in Paraguay, while [50] used a MCDA for assessing the best waste treatment scenario in Mexico. Finally, [51] introduced a MCDA for choosing the best recycling policy suitable for a Brazilian region.

The novelty of the approach consists of the application of a questionnaire survey for assessing the opinion of local stakeholders and actor involved in the MSWM system in parallel with the analysis of quantitative data presented in a simplified way. The main advantage of the method is that it could be replicated and applied in the developing world where there is no data availability and where the experts in the environmental field are not used to consider the problem solving in an integrated manner. The approach is based on the indications provided by previous publications [29, 30, 47], mixed and modified in function of the local context, data availability and the stakeholders involved in the study. Therefore, this paper provided a new integrated tool for assessing the MSWM system following the indication of the international scientific literature.

Though, the method provided a static assessment of future MSWM plans, the research allows providing a first insight about local MSWM challenges, involving local stakeholders, improving awareness and knowledge about possible solutions. The aim is to evaluate the MWSM system for achieving sustainable development, taking into account that sustainability does not depend only on “how much” source separation is carried out, but rather on ‘how’ a source separation level is reached [52].

## 3.3 Discussion

### 3.3.1 MSWM issues in La Paz and the implementation of the CE model

The CE model suggested in this Chapter can be a reliable and applicable theoretical framework for big cities of developing countries. However, financial sustainability, stakeholder inclusion and regulation development are required. Some actions can be introduced for developing the CE in developing cities: Including the informal sector into the solid waste management practices; introducing pre-treatment systems before landfilling, since the putrescible fraction is a real issue in disposal sites, while the recovery of material or energy from waste could be a real missed opportunity; evaluating the possibility to apply new form of SC for municipal hazardous waste for reducing the waste inflow into the landfill and valorizing the materials.

La Paz can be the reference example for introducing MBT plants, since it is a quite low-cost methodology that can solve environmental issues typical of a region with lack of monitoring and difficulties in introducing recycling systems. In addition, in Bolivia, the exploitation of metals recovered by the system can be an appropriate option while a mechanical or manual selection can be introduced. The use of RDF is difficult to be introduced due to the lack of specific regulations about WtE technologies and waste thermal treatment. Therefore, researches should be implemented about this topic.

The main activity suggested for introducing the CE in developing big cities is the involvement of the informal sector into the sanitation system. The results introduced in Section 2 support this activity. Informal recycling activities largely contribute to reduce cost for MSWM and provided livelihood for the urban poor, so it should be recognized as an important element for achieving sustainable MSWM [53, 54]. However, many difficulties will occur in implementing this scenario due to the low rights focused on such informal sector. The inclusion of appropriate measures at institutional levels is recommended, since it represents a crucial factor for informal recycling formalization strategies, increasing the chances of success [55, 56, 57].

OFMSW-SC is also suggested for improving environmental sustainability, although not without difficulties in its application. The implementation of the DtD collection could be a challenge with high expenses and bad results, since the geographical area and the social awareness represent a barrier for developing an effective DtD-SC. Other assessment should be introduced at municipal level for evaluating which areas of the city are most appropriate for applying this strategy, considering that the application of a MBT could be considered always a good solution in case of emergency [19]. Such analysis can be introduced by a GIS.

The main barrier for all scenarios assessed within the Chapter remains the financial sustainability, since local taxes allow covering only 50% of the MSWM system. Other studies found that an increasing charge means less waste disposal and high RR [58], although it could not be considered the best solution since the population could not accept the increase of municipal taxes. However, a fee reduction system, that could be used as an incentive for the users that recycle the most, could be introduced [59]. To plan this management topic, social survey can be a reliable tool for assessing local perception in MSWM activities [60] and planning future reliable collection systems for improving environmental quality and economic development [61].

For summing up, the introduction of the CE model and the analysis of the scenarios suggested that:

1. The inclusion of the informal sector is appropriate for reducing technological complexity and improving cost savings.

2. The introduction of the OFMSW-SC is compulsory for improving the SWM system of the city, for reducing GWP, improving economic sustainability and enhancing the recycling rate. As a second choice, the implementation of an MBT should be considered, and La Paz can be considered suited for its implementation.

3. Local stakeholders are aware of the possible advantages obtainable by the application of MSW-SC since their opinion is mostly in accordance with the quantitative data obtained, although impact assessment should be introduced with advanced approaches.

These considerations can be compared with the findings of other experiences and researches in Latin America and the Caribbean. For example, a study applied in Mexico reported how the inclusion of the informal sector and the application of SC programs, in parallel with the inclusion of the community, are important for improving the MSWM system [62]. While, in Brazil, the cooperative recycling between formal and informal sector was considered an advantage for improving the recovery of recyclable materials if supported by the local government and public policies, suggesting again that the inclusion of the informal recycling sector could be an opportunity [63].

### 3.3.2 Remarks and considerations

The main objective of the Chapter introduced in this research is to discuss the best MSWM scenario suited for the city and to assess main barriers and challenges regarding the introduction of a CE in La Paz. In particular, the parallel assessment of these approaches allows:

a) Assessing different management scenarios for introducing a CE models.

b) Evaluating different MSW collection and treatment systems with the view of local stakeholders.

c) Introducing a critical overview of pros and cons of the collection and treatment methods applicable within the context both in a quantitative and qualitative manner.

Although the approaches applied used many simplifications, the results obtained and the considerations introduced could provide a first view about MSWM issues for developing new plans in La Paz, although with low data availability and awareness on MSWM issues. The analysis of the scenarios by MCDA-questionnaire survey and impacts assessment is suggested for two main reasons:

1. It allows involving local stakeholders, speaking about themes that most of all are not considered within MSWM plans.

2. The comparison between the view of local stakeholders and quantitative data could allow improving the assessment, finding also incorrect opinions or introducing integrated considerations.

The assessment introduced in this Chapter is the first step for analyzing the pros and cons of a new management scenario suited for improving the RR of La Paz. It cannot be considered exhaustive for providing a full assessment of the current MSWM system implement at municipal level and for assessing future scenario. Therefore, following this approach, the next researches presented in Chapter 4 will be focused on the implementation of a questionnaire survey for assessing the behavior of the citizens about environmental issues and MSW-SC systems, the application of a complete LCA of the scenarios assessed, in order to compare the results obtained with a more structured environmental impacts assessment, and the use of GIS for assessing the potential collection improvements and the main barriers to the introduction of new treatment systems. Moreover, the implementation of a effective SC system at the University provides the last indication on the opportunities and challenges for implementing recycling actions and policies in public areas.

The integrated analyses implemented by these methods will provide a full insight about the local challenges for improving the MSWM system and for introducing the principle of the SDGs and CE. Then, the results will be used for introducing the international cooperation projects for improving the MSWM system of the city.

# Bibliography


[1] Ferronato, N., Rada, E. C., Portillo, M. A. G., Cioca, L. I., Ragazzi, M., & Torretta, V. (2019). Introduction of the circular economy within developing regions: A comparative analysis of advantages and opportunities for waste valorization. Journal of environmental management, 230, 366-378.

[2] Ferronato N., M. Ragazzi, M. A. P. Gorritty, E. G. G. Lizarazu, P. Viotti, V. Torretta (2019) How to improve Recycling Rate in Developing big cities: An Integrated Approach for assessing Municipal Solid Waste Collection and Treatment Scenarios. Environmental Development

[3] Surampalli, R. Y., Zhang, T. C., Tyagi, R. D., & Selvam, A. (2016, January). Sustainable solid waste management. American Society of Civil Engineers.

[4] Letcher, T. M., & Vallero, D. A. (Eds.). (2019). Waste: A handbook for management. Academic Press.

[5] Kumar, S. (2016). Municipal solid waste management in developing countries. CRC Press.

[6] Christensen, T. (Ed.). (2011). Solid waste technology and management. John Wiley & Sons.

[7] ISWA - International solid waste assosiation (2016) A Roadmap for closing Waste Dumpsites. The World's most Polluted Places.

[8] Alam, R., Chowdhury, M.A.I., Hasan, G.M.J., Karanjit, B., Shrestha, L.R., 2008. Generation, storage, collection and transportation of municipal solid waste–A case study in the city of Kathmandu, capital of Nepal. Waste Manage. 28, 1088-1097.

[9] Ragazzi, M., Catellani, R., Rada, E.C., Torretta, V., Salazar-Valenzuela, X., 2014. Management of municipal solid waste in one of the Galapagos Islands. Sustainability. 6, 9080-9095.

[10] Wilson, D.C., Araba, A.O., Chinwah, K., Cheeseman, C.R., 2009. Building recycling rates through the informal sector. Waste Manage. 29, 629-635.

[11] Sembiring, E., Nitivattananon, V., 2010. Sustainable solid waste management toward an inclusive society: Integration of the informal sector. Res., Cons. Recy. 54, 802-809.

[12] Silva de Souza Lima, N., Mancini, S. D., 2017. Integration of informal recycling sector in Brazil and the case of Sorocaba City. Waste Manage. Res. 35, 721-729.

[13] Vaccari, M., Perteghella, A., 2016. Resource recovery from waste by Roma in the Balkans: A case study from Zavidovici (BiH). Waste Manage. Res. 34, 866-874.

[14] Vaccari, M., Torretta, V., Collivignarelli, C., 2012. Effect of improving environmental sustainability in developing countries by upgrading solid waste management techniques: A case study. Sustainability. 4, 2852-2861.

[15] Munnich, K., Mahler, C.F., Fricke, K., 2006. Pilot project of mechanical-biological treatment of waste in Brazil. Waste Manage. 26, 150–157.

[16] Ravindra, K., Kaur, K., Mor, S., 2015. System analysis of municipal solid waste management in Chandigarh and minimization practices for cleaner emissions. J. Clean. Prod. 89, 251-256.

[17] Scaglia, B., Confalonieri, R., D'Imporzano, G., Adani, F., 2010. Estimating biogas production of biologically treated municipal solid waste. Bioresource technol. 101, 945-952.

[18] Torretta, V., Ferronato, N., Katsoyiannis, I. A., Tolkou, A. K., Airoldi, M., 2016. Novel and Conventional Technologies for Landfill Leachates Treatment: A Review. Sustainability. 9, 9

[19] Trulli, E., Ferronato, N., Torretta, V., Piscitelli, M., Masi, S., Mancini, I., 2018. Sustainable mechanical biological treatment of solid waste in urbanized areas with low recycling rates. Waste Manage. 71, 556-564.

[20] Gu, Y., Wu, Y., Xu, M., Wang, H., Zuo, T., 2016. The stability and profitability of the informal WEEE collector in developing countries: A case study of China. Resour. Conserv. Recy. 107, 18-26.

[21] Chi, X., Streicher-Porte, M., Wang, M.Y., Reuter, M.A., 2011. Informal electronic waste recycling: a sector review with special focus on China. Waste Manage. 31, 731-742.

[22] Egeonu, N., Herat, S. 2016. E-waste: a problem or an opportunity? Review of issues, challenges and solutions in African countries. Int. J. Environ. Waste Manage. 17, 318-339.

[23] Cesaro, A., Belgiorno, V., Vaccari, M., Jandric, A., Chung, T.D., Dias, M.I., Hursthouse A., Salhofer, S., 2017. A device-specific prioritization strategy based on the potential for harm to human health in informal WEEE recycling. Environ. Sci. Pollut. R. 25, 683-692.

[24] Storey, D., Santucci, L., Fraser, R., Aleluia, J., Chomchuen, L., 2015. Designing effective partnerships for waste-to-resource initiatives: Lessons learned from developing countries. Waste Manage. Res. 33, 1066-1075.

[25] Ionescu, G., Rada, E.C., Ragazzi, M., Mărculescu, C., Badea, A., Apostol, T., 2013. Integrated municipal solid waste scenario model using advanced pretreatment and waste to energy processes. Energy Convers. Manag. 76, 1083–1092. https://doi.org/10.1016/j.enconman.2013.08.049

[26] Liu, Y., Xing, P., Liu, J., 2017. Environmental performance evaluation of different municipal solid waste management scenarios in China. Resour. Conserv. Recycl. 125, 98–106. https://doi.org/10.1016/j.resconrec.2017.06.005

[27] Achillas, C., Moussiopoulos, N., Karagiannidis, A., Banias, G., Perkoulidis, G., 2013. The use of multi-criteria decision analysis to tackle waste management problems: a literature review. Waste Manag. Res. 31, 115–29. https://doi.org/10.1177/0734242X12470203

[28] Hanan, D., Burnley, S., Cooke, D., 2013. A multi-criteria decision analysis assessment of waste paper management options. Waste Manag. 33, 566–573. https://doi.org/10.1016/j.wasman.2012.06.007

[29] Oyoo, R., Leemans, R., Mol, A.P.J., 2013. The determination of an optimal waste management scenario for Kampala, Uganda. Waste Manag. Res. 31, 1203–1216. https://doi.org/10.1177/0734242X13507307

[30] Jovanovic, S., Savic, S., Jovicic, N., Boskovic, G., Djordjevic, Z., 2016. Using multi-criteria decision making for selection of the optimal strategy for municipal solid waste management. Waste Manag. Res. 34, 884–95. https://doi.org/10.1177/0734242X16654753

[31] Leme, M.M.V., Rocha, M.H., Lora, E.E.S., Venturini, O.J., Lopes, B.M., Ferreira, C.H., 2014. Techno-economic analysis and environmental impact assessment of energy recovery from Municipal Solid Waste (MSW) in Brazil. Resour. Conserv. Recycl. 87, 8–20. https://doi.org/10.1016/j.resconrec.2014.03.003

[32] Rasapoor, M., Adl, M., Pourazizi, B., 2016. Comparative evaluation of aeration methods for municipal solid waste composting from the perspective of resource management: A practical case study in Tehran, Iran. J. Environ. Manage. 184, 528–534. https://doi.org/10.1016/j.jenvman.2016.10.029

[33] Ministerio de Medio Ambiente y Agua (MMAyA), 2011. Viceministerio de agua potable y saneamiento básico. Diagnóstico de la gestión de residuos sólidos en el Departamento de La Paz, Dirección general de gestión integral de residuos sólidos. [In Spanish]. Available at: http://www.anesapa.org/wpcontent/uploads/2014/07/ DIAGNOSTICODEPARTAMENTAL-LA-PAZ.pdf

[34] Hettiarachchi, H., Ryu, S., Caucci, S., and Silva, R. (2018). Municipal Solid Waste Management in Latin America and the Caribbean: Issues and Potential Solutions from the Governance Perspective. Recycling, 3(2), 19.

[35] Wilson, D.C., Rodic, L., Scheinberg, a., Velis, C. a., Alabaster, G., 2012. Comparative analysis of solid waste management in 20 cities. Waste Manag. Res. 30, 237–254. https://doi.org/10.1177/0734242X12437569

[36] European Commission, 2015. Assessment of separate collection schemes in the 28 capitals of the EU, Final Report. BiPRO/CRI 2015.

[37] Montejo, C., Tonini, D., Márquez, M. del C., Fruergaard Astrup, T., 2013. Mechanical-biological treatment: Performance and potentials. An LCA of 8 MBT plants including waste characterization. J. Environ. Manage. 128, 661–673. https://doi.org/10.1016/j.jenvman.2013.05.063

[38] Lohri, C.R., Camenzind, E.J., Zurbrügg, C., 2014. Financial sustainability in municipal solid waste management - Costs and revenues in Bahir Dar, Ethiopia. Waste Manag. 34, 542–552. https://doi.org/10.1016/j.wasman.2013.10.014

[39] Schneider, P., Lämmel, A., Schmitt, A., Nam, N.P., Anh, L.H., 2017. Current and future solid waste management system in Northern Viet Nam with focus on Ha Noi: climate change effects and landfill management. J. Mater. Cycles Waste Manag. 19, 1106–1116. https://doi.org/10.1007/s10163-016-0551-7

[40] Themelis, N.J., Ulloa, P.A., 2007. Methane generation in landfills. Renew. Energy 32, 1243–1257. https://doi.org/10.1016/j.renene.2006.04.020

[41] Ragazzi, M., Maniscalco, M., Torretta, V., Ferronato, N., Rada, E.C., 2017. Anaerobic digestion as sustainable source of energy: A dynamic approach for improving the recovery of organic waste. Energy Procedia 119, 602–614. https://doi.org/10.1016/j.egypro.2017.07.086

[42] Boucher, O., Friedlingstein, P., Collins, B., Shine, K.P., 2009. The indirect global warming potential and global temperature change potential due to methane oxidation. Environ. Res. Lett. 4. https://doi.org/10.1088/1748-9326/4/4/044007

[43] Srivastava, V., Ismail, S.A., Singh, P., Singh, R.P., 2015. Urban solid waste management in the developing world with emphasis on India: challenges and opportunities. Rev. Environ. Sci. Bio-Technology 14, 317–337. https://doi.org/10.1007/s11157-014-9352-4

[44] Turner, D.A., Williams, I.D., Kemp, S., 2015. Greenhouse gas emission factors for recycling of source-segregated waste materials. Resour. Conserv. Recycl. 105, 186–197. https://doi.org/10.1016/j.resconrec.2015.10.026

[45] Rigamonti, L., Grosso, M., Giugliano, M., 2009. Life cycle assessment for optimising the level of separated collection in integrated MSW management systems. Waste Manag. 29, 934–944. https://doi.org/10.1016/j.wasman.2008.06.005

[46] Marshall, R.E., Farahbakhsh, K., 2013. Systems approaches to integrated solid waste management in developing countries. Waste Manag. 33, 988–1003. https://doi.org/10.1016/j.wasman.2012.12.023

[47] Goulart Coelho, L.M., Lange, L.C., Coelho, H.M.G., 2017. Multi-criteria decision making to support waste management: A critical review of current practices and methods. Waste Manag. Res. 35, 3–28. https://doi.org/10.1177/0734242X16664024

[48] Guarnieri, P., Sobreiro, V.A., Nagano, M.S., Marques Serrano, A.L., 2015. The challenge of selecting and evaluating third-party reverse logistics providers in a multicriteria perspective: A Brazilian case. J. Clean. Prod. 96, 209–219. https://doi.org/10.1016/j.jclepro.2014.05.040

[49] Blanco, G., Amarilla, R., Martinez, A., Llamosas, C., Oxilia, V., 2017. Energy transitions and emerging economies: A multi-criteria analysis of policy options for hydropower surplus utilization in Paraguay. Energy Policy 108, 312–321. https://doi.org/10.1016/j.enpol.2017.06.003

[50] Taboada-González, P., Aguilar-Virgen, Q., Ojeda-Benítez, S., Cruz-Sotelo, S., 2014. Application of analytic hierarchy process in a waste treatment technology assessment in Mexico. Environ. Monit. Assess. 186, 5777–5795. https://doi.org/10.1007/s10661-014-3819-1

[51] Gomes, C.F.S., Nunes, K.R.A., Helena Xavier, L., Cardoso, R., Valle, R., 2008. Multicriteria decision making applied to waste recycling in Brazil. Omega 36, 395–404. https://doi.org/10.1016/j.omega.2006.07.009

[52] Consonni, S., Giugliano, M., Massarutto, A., Ragazzi, M., Saccani, C., 2011. Material and energy recovery in integrated waste management systems: Project overview and main results. Waste Manag. 31, 2057–2065. https://doi.org/10.1016/j.wasman.2011.04.016

[53] Diaz, R., Otoma, S., 2013. Cost–benefit analysis of waste reduction in developing countries: a simulation. J. Mater. Cycles Waste Manag. 16, 108–114. https://doi.org/10.1007/s10163-013-0148-3

[54] Velis, C.A., Wilson, D.C., Rocca, O., Smith, S.R., Mavropoulos, A., Cheeseman, C.R., 2012. An analytical framework and tool ('InteRa') for integrating the informal recycling sector in waste and resource management systems in developing countries. Waste Manag. Res. 30, 43–66. https://doi.org/10.1177/0734242X12454934

[55] Aparcana, S., 2017. Approaches to formalization of the informal waste sector into municipal solid waste management systems in low- and middle-income countries: Review of barriers and success factors. Waste Manag. https://doi.org/10.1016/j.wasman.2016.12.028

[56] Fei, F., Qu, L., Wen, Z., Xue, Y., Zhang, H., 2016. How to integrate the informal recycling system into municipal solid waste management in developing countries: Based on a China's case in Suzhou urban area. Resour. Conserv. Recycl. 110, 74–86. https://doi.org/10.1016/j.resconrec.2016.03.019

[57] Jaligot, R., Wilson, D.C., Cheeseman, C.R., Shaker, B., Stretz, J., 2016. Applying value chain analysis to informal sector recycling: A case study of the Zabaleen. Resour. Conserv. Recycl. 114, 80–91. https://doi.org/10.1016/j.resconrec.2016.07.006

[58] Welivita, I., Wattage, P., Gunawardena, P., 2015. Review of household solid waste charges for developing countries - A focus on quantity-based charge methods. Waste Manag. https://doi.org/10.1016/j.wasman.2015.08.018

[59] Miezah, K., Obiri-Danso, K., Kádár, Z., Fei-Baffoe, B., Mensah, M.Y., 2015. Municipal solid waste characterization and quantification as a measure towards effective waste management in Ghana. Waste Manag. 46, 15–27. https://doi.org/10.1016/j.wasman.2015.09.009

[60] De Feo, G., Williams, I.D., 2013. Siting landfills and incinerators in areas of historic unpopularity: Surveying the views of the next generation. Waste Manag. 33, 2798–2810. https://doi.org/10.1016/j.wasman.2013.08.019

[61] Hudson, A., 2017. Restoring and Protecting the world's large marine ecosystems: An engine for job creation and sustainable economic development. Environ. Dev. https://doi.org/10.1016/j.envdev.2016.10.003

[62] Valencia-Vázquez, R., Pérez-López, M.E., Vicencio-de-la-Rosa, M.G., Martínez-Prado, M. a, Rubio-Hernández, R., 2014. Knowledge and technology transfer to improve the municipal solid waste management system of Durango City, Mexico. Waste Manag. Res. 32, 848–56. https://doi.org/10.1177/0734242X14546035

[63] Gutberlet, J., 2015. Cooperative urban mining in Brazil: Collective practices in selective household waste collection and recycling. Waste Manag. 45, 22–31. https://doi.org/10.1016/j.wasman.2015.06.023

# Chapter 4

# Management tools and methods for planning the CE principles

*- In a Circular Economy the objective is to maximize value at each point in a product’s life making the goods of today the resource of tomorrow at yesterday’s prices, creating new jobs and systems at each step -*
*Stahel R. Walter (Nature, 2016)*

## Introduction

The aim of this Chapter is to introduce the management tools for planning and assessing the SWM system in developing big cities, where the lack of data, low economic sustainability and difficulties in urban planning are barriers that should be overcome. The methods were implemented in La Paz, in order to demonstrate its usefulness and reliability if implemented with an integrated approach. The tools introduced regards the implementation of social surveys at city level, for assessing citizens’ behavior in formal and informal recycling, the use of LCA and MFA, for analyzing the environmental impacts of future managements scenarios, the implementation of GIS, for commenting the reliability of the scenarios in function of the geographical characteristics of the city, the implementation of SCS in public Universities, for critically analyzing the main barriers for implementing reliable SCS in public areas, and the implementation of an integrated indicator set for assessing the waste separation at the source of HW, in order to improve its treatment and final disposal. The Chapter is divided in five sections, where the methods are explained and the results are commented. Finally, a Discussion section is introduced in order to comment the importance of implementing these approaches for introducing new waste management plans and international cooperation projects, with the aim to improve the quality of the SWM system of a developing city and, as consequence, its environmental, social and economic sustainability. The social survey was presented at the $7^{th}$ international conference of sustainable SWM (Heraklion, Greece, 2019) and considered for publication in scientific Journals; The GIS analysis was submitted to the "*Waste Management*" Journal, as well as the SCS implemented at the university: They are currently under review (Minor - Major Revisions). Finally, the HW indicators were presented at the $6^{th}$ international conference of sustainable SWM (Naxos, Greece, 2018) and published in the "*Waste Management&Research*" - WM&R) Journal [1], while the LCA was submited to the WM&R journal and it is currently under review.

## 4.1 Citizens' behavior about formal and informal recycling: Questionnaire surveys as assessment tool

This research refers to the article *"Formal and informal selective collection towards circular economy: assessment of citizens' involvement in Bolivia"* (Ferronato N., Gorritty Portillo M.A., Guisbert Lizarazu G.E. and Torretta V.) presented at the 7th conference on Sustainable solid waste management (Heraklion, Crete - 2019) and selected for possible publication in scientific journals. It is currently under review.

### 4.1.1 Introduction

The success of recycling programs, both formal and informal, depends on households' participation [2], and one of the main barriers is the lack of knowledge about environmental impacts and the importance of waste separation at the source [3]. Many social factors should be considered in order to cope with population's requirements: Households' income, awareness about recycling facilities [2], the distance from home to the collection site [4], the level of environmental knowledge [5] and the attitude to waste separation [3], are all drivers of waste separations behavior. As a result, for developing new recycling policies, information about the status of residents' attitudes should be gathered [6].

Questionnaire survey is a useful method for assessing households' attitudes to recycling and for planning formal or informal SCS in low-middle income developing cities. In Dhaka, Bangladesh, a questionnaire survey submitted to 456 households was implemented for assessing households' attitudes toward recycling, suggesting citizens' inclusion toward sustainable SWM [7]; In Bangkok, Thailand, 93 public and private office workers residing in the city were interviewed by questionnaire, and results advise to promote people's engagement in each type of MSW management, establishing different communication campaigns for each SCS implemented [8]; In China, a survey of 100 villages, with 679 valid sample households, suggests that the presence of organized final disposal sites strongly encourages proper disposal behavior, encouraging infrastructural developments for improving environmental protection [9]; In Brazil, 459 interviews was obtained to estimate waste from WEEE generation taking into consideration the different social and economic status and producing local primary data about waste quantities [10]; In Berekum municipality, Ghana, 312 households were interviewed by a questionnaire survey, indicating that the effective MSWM requires transparency, negotiations and engagement between different stakeholders [129]. Therefore, social survey is a useful tool for obtaining information about waste generation and households' attitudes in developing cities where data are still lacking.

In Bolivia, a first issue that should be overcome for introducing SCS in developing cities is the provision of MSW infrastructures, as common in other low-middle income countries [12]. Other concerns, typical of developing countries, regards the lack of awareness and involvement of the population, uncollected fee, environmental and health impacts due to open burning or open dumping and insufficient environmental policies [13], which means emissions of carbon dioxide equivalent, carbon monoxide, sulfur dioxide, nitrite oxide, and particulate matter, among others [14]. This part of the research introduces a questionnaire survey in La Paz for planning the introduction of new infrastructures for improving the SCS, considering social attitudes and habits in recycling and the presence of the informal recycling.

The research refers to the recycling behavior of the citizens of La Paz, where the introduction of CE policies and plans are still under development [72]. The aim of the work is to assess the behavior of the citizens concerning the formal recycling points available in the city, comparing the results obtained with another study conducted in parallel at municipal level. The questionnaire survey investigates why and how the citizens implement the SC, understanding if the population is used to deliver the recyclable waste also to the informal collection, which is not still included in the formal MSW management system, as typical in developing countries [16, 17].

The research was conducted in 2018 for supporting the requirements of the GAMLP, which intends to improve the RR of the city for reducing environmental impacts and improving economic sustainability, as well as social inclusion. The results obtained allowed introducing a SCS in two neighborhoods of the La Paz, starting the first massive pilot plan for improving the RR of the city. Apart from the case study, the novelty of the research is the implementation of a questionnaire survey before the introduction of a formal SCS at pilot scale, providing an example of the usefulness of this method for planning new recycling plans.

### 4.1.2 Methods

The survey was conducted at the GP and through the streets of the neighborhoods in order to assess the recycling behavior of the users of the GP and of the citizens. Therefore, two structured questionnaires were built. The face-to-face method was employed since it was the only way useful for detecting the users of the GP. The same method was replicated for the interviews implemented in the neighborhoods.

For the implementation of the survey campaigns, 10 students of the University, volunteers who supported the research, were trained and involved for providing the questionnaire to the citizens (Figure 4.1). The questionnaire survey was implemented during the Sunday morning, from 9 am to 1 pm, for a total of 13 weeks (from January to April 2018). The day and the hours considered for the survey are the same of the activity of the GP. The areas for the surveys were pre-determined and planned for making the results representative both for the GP and the municipality.


**Figure 4.1:** Volunteers who participated to the research.

The interviews were conducted with people from 18 to about 75 years old, selected from the users of the GP and the citizens in function of their availability to participate in the interview. The motivation of the questionnaire was carefully introduced to the citizens before its submission, so interviews only proceeded when respondents provided informed agreement. The average response rate was about 80%, higher for the users of the green points (90%) than for the citizens stopped in the neighborhoods (60%). Before the implementation of the campaigns, a pre-test with about 50 people was implemented in order to detect possible errors in the formulation of the questions, as well as the willingness of the citizens to answer the queries and the difficulty level or un-clarity of the questions.

The data collected were systematized in a calculation platform (excel) and coded in agreement with the number of questions provided and type of questionnaire. The results were analyzed with the software R-studio and the excel platform in order to implement the statistical analysis and generate the graphics of the results.

**Sample size and location of the interviews**

In order to generalize the data obtained for the whole population, a confidence interval (CI) with 95% confidence level was introduced for each question. The population size for both study areas was calculated to obtain a CI lower than five. These assumptions were used in the following sample size formulas [18], used by other authors [6]:

$$ss' = \frac{Z^2\,(p\,(1-p)\,)}{d^2} \tag{4.1.1}$$

Where Z is the Z value (1.96 for 95% confidence level), p is the percentage of respondents who selected a choice, expressed as a decimal (0.5 was used as the worst case of response – binary answer) and d is the confidence interval, expressed as a decimal (in this study considered as 0.05). Equation 4.1.1 was used for obtaining the finite number of families for La Paz:

$$SS = \frac{ss'}{1 + \frac{ss'-1}{F}} \tag{4.1.2}$$

Where F id the number of inhabitants of La Paz, for the first questionnaire, and the number of users of the GP, for the second one. As regard the municipal survey, the sample size was calculated in function of the 900,000 inhabitants of the city. Therefore, following the results of equation 4.1.2, 384 citizens should be interviewed. Totally, 410 citizens answered to the questionnaire survey, obtaining a maximum CI lower than 5. The neighborhoods considered for the study were 23. For optimizing the time required for the study, 11 points were selected for the campaigns. The 11 neighborhoods were choose considering both the north and south part of the city, in order to obtain a sample that can be considered representative of the city. Moreover, the points were selected in areas of high-density population (i.e. supermarkets, bus stops, graveyard, markets, squares), and near the areas where the GP are located. In Figure 4.2 is reported the field work implemented in La Paz.

The data available at the GP were the quantity of recyclable materials collected per year and the average number of families who provided the waste per Sunday. The GP were divided in a north, central and south area, representative for the development of the city, from the less (the north) to the most developed (the south). Data are reported in Figure 4.3. Can be noted that the quantities of waste and the number of families that deliver the waste per week are proportionate and are higher in the south area of La Paz, the richer of the city.

These data were used for counting how many families should be interviewed per

**Figure 4.2:** Submission of the questionnaires to the citizens.

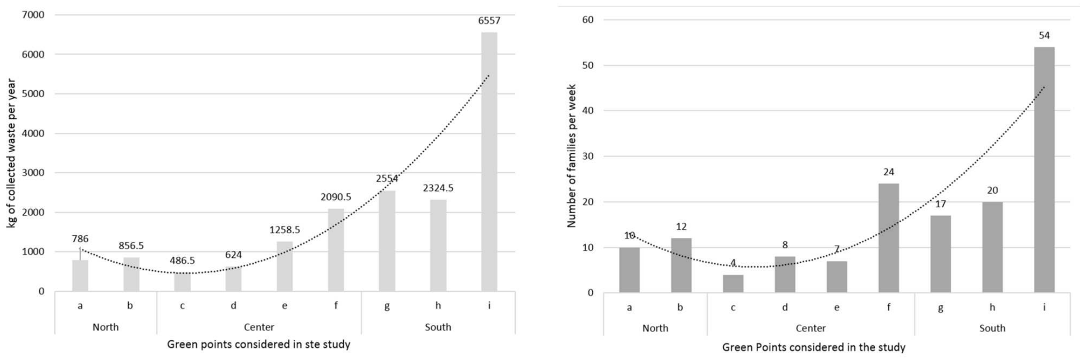


**Figure 4.3:** Submission of the questionnaires to the citizens.

GP. The total sample size was calculated in function of the total users of the GP, about 4,600 families, which is about 2% of the population. Again, as result of equation 4.1.2, the total sample size is of 354 users. The proportion of each point and the sample interviewed are reported in Table 4.1.

| | GP where the survey took place | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | a | b | c | d | e | f | g | h | i | Total |
| Theoretical sample size | 23 | 27 | 9 | 18 | 16 | 54 | 39 | 45 | 123 | 354 |
| Sample interviewed | 18 | 23 | 8 | 13 | 21 | 90 | 18 | 54 | 118 | 364 |
| Days required for the interviews | 1 | 2 | 1 | 2 | 3 | 2 | 3 | 3 | 3 | |

**Table 4.1:** Theoretical sample size considered in function of the number of users per GP compared with the sample interviewed.

The real data available allow planning also the days required for interviewing the sample per GP in order to achieve a sample statistically significant. However, to obtain the exact user number per point was logistical difficult, due to the variable number of users which delivered the waste per Sunday. For this reason, the real number of the sample size per GP are not perfected related to the theoretical. Finally, the total sample interviewed was 364 families. Figure 4.4 reported the maps with the GP and the districts considered for the interviews. At the end of the survey campaigns, 774 citizens were interviewed.

#### Questionnaires

The questionnaires were implemented for the GP and the neighborhoods. In both cases, the personal attributes were evaluated, in terms of gender, age, people per family and socioeconomic status. In particular, the socioeconomic status was determined in function of the job and was divided in four main categories:

A Jobs where a graduation is required or where the economic level is high (lawyer, engineer, professor, ambassador. . . )

B Jobs where a higher education level is required or where the economic level could be associated to the middle class (secretary, government employee, owner of a business, professional sports man . . . )

C Retired or University students

D Jobs where the scholar level is low as well as the economic level (bricklayer, electrician, newsagent, baker. . . )

This categories division was introduced since, during the first implementation of the questionnaire, there were difficulties by the interviewed to provide personal information about the salary and the scholar level. So, the questions were modified for obtaining at least an indication of a socioeconomic status.


**Figure 4.4:** GP (left) and districts (right) where the social surveys were implemented.

#### A. Questionnaire at the GP

The first questionnaire included eight questions ($Q_i$), while the second is composed of seven ones. The main conceptual difference between the two questionnaire is that for the GP the users surely implement the formal waste selective collection, so the questions are related to understand how they implement this practice; while in the second questionnaire, where there are no previous information provided by the context, the data gathered are related to the knowledge of the GP and the implementation of the SCS at home. In both cases, the questionnaires were implemented for assessing a few factors that influences the behavior of the citizens and for detecting some information required for the application of a SCS.

At the GP, the factors influencing the recycling behavior were assessed in function of previous information collected by the local government, while the unknown information was introduced for understanding citizens' opinion and behaviors. For the GP, three factors were assessed:

- Factor 1 (F1): the citizens who deliver the material live nearer than 500 m from the GP,
- Factor 2 (F2): the users of the GP are mainly of high education level,
- Factor 3 (F3): the users deliver the waste more than one time per month.

One important information regards the delivery of the waste also in other informal collection points. At the same time, understand how the citizens knew the operation of the formal collection system, what they think about the need of other GP, and why they implement the selective collection are also information requested by the local government for planning the municipal SCS.

Therefore, the questionnaire was divided in five sections, the first for analyzing the personal attributes, while the others for assessing where they live (Location), the delivering behavior (Delivering), the knowledge about the GP (Knowledge), and the view about the SCS (Opinion). These topics were assessed in order to understand: how far the GP or separate containers could be introduced; how many times per month the people use the GP, so if the GP should be fixed or is enough introduce it each Sunday; how the population knows the activity of the GP, for understanding which kind of public campaigns should be introduced; if they think that other GP are required and why they implement the selective collection, for planning publicity and the implementation of other selective collection areas.

**B. Questionnaires at the neighborhoods**

The questionnaire submitted at the neighborhoods wants to find some indications about the coexistence of the formal and informal collection. The factors assessed are:

- Factor 4 (F4): less than 2% of the interviewed use the GP,
- Factor 5 (F5): More than 2% of the population do the selective collection at home,
- Factor 6 (F6): The citizens deliver the recyclable waste to the informal recycling shops.

The interest of the local Government was about the typology of waste segregated, where the citizens delivered the recyclable waste selected and why they do that. The main objective is to assess if a part of the population can be immediately involved in the formal SCS and how it should be introduced. For this reason, the questionnaire was divided in three main part: The first for assessing the personal attributes, as for the questionnaire provided at the GP, the second for asking about the GP, so for evaluating how many people know the presence of the GP but do not use them, and the last for assessing the recycling behavior at home, so for understanding if the population do or do not implement the selective collection. The questions, of both questionnaires, are listed in Table 4.2.

| Aspect | No. | Question | Choices for each question |
|---|---|---|---|
| | | **Green points** | |
| Personal attributes | | Gender | Male/Female. |
| | | Age | <21; 21-30; 31-40; 41-50; 51-60; 61-70; 71-80. |
| | | People per family | 1; 2; 3; 4; 5; 6; >6. |
| | | Socioeconomic status | A; B; C; D. |
| Location | $Q_1$ | Do you live in this area of the city? | Yes; No. |
| | $Q_2$ | How far do you live from here? | <250 m; <500 m; <1 km; >1 km. |
| Delivering | $Q_3$ | How many times per month do you deliver the waste? | 1; 2; 3; 4; 5. |
| | $Q_4$ | Do you deliver the waste only to the green points? | Yes; No. |
| | $Q_5$ | When did you start to deliver the waste to the GP? | < 3 months ago; 3-6 months ago; 6-12 months ago; more than 1 year ago; 2-3 years ago; When the selected collection started |
| | $Q_6$ | How did you know the operation of the GP? | Publicity; speaking with the family/friends; in television; walking; other. |
| | $Q_7$ | In your opinion, other GP are required in the city? | No, more points are not required; yes, more points are required; more collection time and more days are required; Yes, more points are required as well as more collection time. |
| | $Q_8$ | Why do you do the selective collection of the MSW? | For the environment; for cleaning the city; save space at home; recycling the waste; personal education; do what the municipality say; other. |
| | | **Neighbourhoods** | |
| Personal attributes | | Gender | Male/Female. |
| | | Age | <21; 21-30; 31-40; 41-50; 51-60; 61-70; 71-80. |
| | | People per family | 1; 2; 3; 4; 5; 6; >6. |
| | | Socioeconomic status | A; B; C; D. |
| Knowledge of the GP | $Q_1^N$ | Do you know the GP for the collection of the recyclable waste? | Yes; No. |
| | $Q_2^N$ | How did you know the GP? | Publicity; speaking with the family/friends; in television; walking; others. |
| | $Q_3^N$ | Do you use the GP? | Yes; No. |
| Recycling behavior | $Q_4^N$ | Do you do the selective collection at home? | Yes; No. |
| | $Q_5^N$ | How do you separate the recyclable materials? | Paper; Cardboard; Paper & Cardboard; PELD & PET; PEHD; All plastics together; Cans; White glass, colored glass; all glass together; Organic waste separated; Organic waste all together; WEEE; batteries. |
| | $Q_6^N$ | Where do you deliver the recyclable materials selected at home? | Sold to the informal sector; Left on the road; always at the green points; other uses; mixed containers; separate containers; gave to the informal sector; exchanged with other products; accumulated; used in the workplace; Burned; to the animals (organic waste). |
| | $Q_7^N$ | Why do you do the selective collection of the solid waste at home? | For the environment; cleanness of the city; save space at home; recycling the waste; to accomplish with what the government said; other. |

**Table 4.2:** Face to face questionnaire provided to the 774 citizens at the GP and districts.

#### Data analysis

The study participants' answers were analyzed using descriptive statistics. While quantitative variables were introduced as mean ± standard deviation (SD), the others were expressed as average percentage providing its CI. The Chi-square ($\chi^2$) test for independence was used in order to determine whether some answers were related to each other. For the questionnaire survey submitted to the citizens, a binomial logistic regression was performed for testing the people per households, gender, age and social-economic status for predicting the selective collection compliance (formal or informal), the knowledge and the use of the GP. A 2-sided p-value less than 0.05 was considered to be significant ($p < 0.05$).

### 4.1.3 Results

#### Characteristics of the respondents

The people interviewed at the GP are representative of the users, while the ones interviewed at district level, chose trying to balance the sample in terms of age, gender and socioeconomic status, are representative of the population. Table 4.3 reports the descriptive statistic and CI of the socioeconomic status of the respondents.

Most of the people interviewed at the GP are female (62.6%, CI 4.93), with a socioeconomic status of class A (45.6%, CI 4.27). The average age of the people interviewed is 48.8 ±14.9 years old, with the majority between 30-60 years old (63.9%, CI 3.46).

At the neighborhoods, the gender considered is balanced, with 51.7% male and 48.3% female (CI 4.84), as well as the socioeconomic status which is 31.3% of class A, 21.8% class B, 26.9% class C and 20% class D (CI 4.19). The population average age is quite similar for both questionnaires. It is 48.8 ±14.9 years old for the sample interviewed at the neighborhoods and 42.4 ±16.4 years old for the users of the GP. Similarly, also the people per family could be considered comparable, since they are 4.1 ±1.6 at the neighborhoods and 3.55 ±1.49 at the GP, on average.

#### Users of the GP

The users of the GP live mostly in the district where the points are located (75.8%, CI 4.93). In particular, 48.6% (CI 4.27) live not farer than 250 m and 22.3% live between 250 m and 500 m. Only the 17.3% live in another district and farther than 1 km from the GP, so they recycle due to a strong attitude. About 29.8% (CI 3.94) of the users provide the recyclable waste every week, the majority (59%), deliver it one or two times per month. As reported by other authors, this behavior could be due to the numerosity of the people per family, the proximity to the GP or the socioeconomic status, which influenced the amount of waste produced per day (Khan et al., 2016). However, in La Paz, there is not any statistical dependence about these three factors, nor for the family number ($\chi^2_{[4]} = 4.28$, p = 0.37), for the closeness ($\chi^2_{[12]} = 5.3$, p = 0.9) and for the socioeconomic status ($\chi^2_{[12]} = 9.1$, p = 0.7). It means that the factors influencing the delivery time should depend to other factors which were not considered in this research.

As regard $Q_4$ (Do you deliver the waste only to the green points?), 89% (CI 4.93) of the interviewed answered positively, so that they delivered the recyclable waste only at the GP, while 11% use also other GP or sell it to the informal recycling shops. It means that the citizens who use the formal SCS is used to complain only with it.

The GP are available to the public from 2014, so about four years before the implementation of this social survey (January to April 2018). About 66.5% (CI 3.67) of the users started to use the GP before 2017 ($Q_5$ - When did you start to deliver the waste to the GP?), so when the project introduced by the NGO was still in action. Therefore, less than 35% of the users were involved in the last year (2017). It means that after the project the involvement of the population started to decrease, in accordance with the reduction of the GP and public campaigns.

In relation with $Q_5$, $Q_6$ (How did you know the operation of the GP?) was analyzed. Results reported that 53.3% (CI 3.1) of the users knew the GP walking through the city, seeing the activity of the GP during the Sunday. Only 32.4% stated that they knew the SCS by the publicity, in various form. The relation between when the users started to use the GP and how they known the GP is statistically significant ($\chi^2_{[40]} = 57.706$, p = 0.035) and it is schematically reported in Figure 4.5. The figure reports the percentage of people that knew the GP (i.e. walking through the city) during the years (ex. About 30% of the people that knew the GP by the publicity was informed in 2014, while less than 5% three months before the questionnaire survey). It shows how the majority of the people that knew the formal SCS by the publicity or in television, started to use it in 2014, while during the years the amounts decreased to less than 5%.

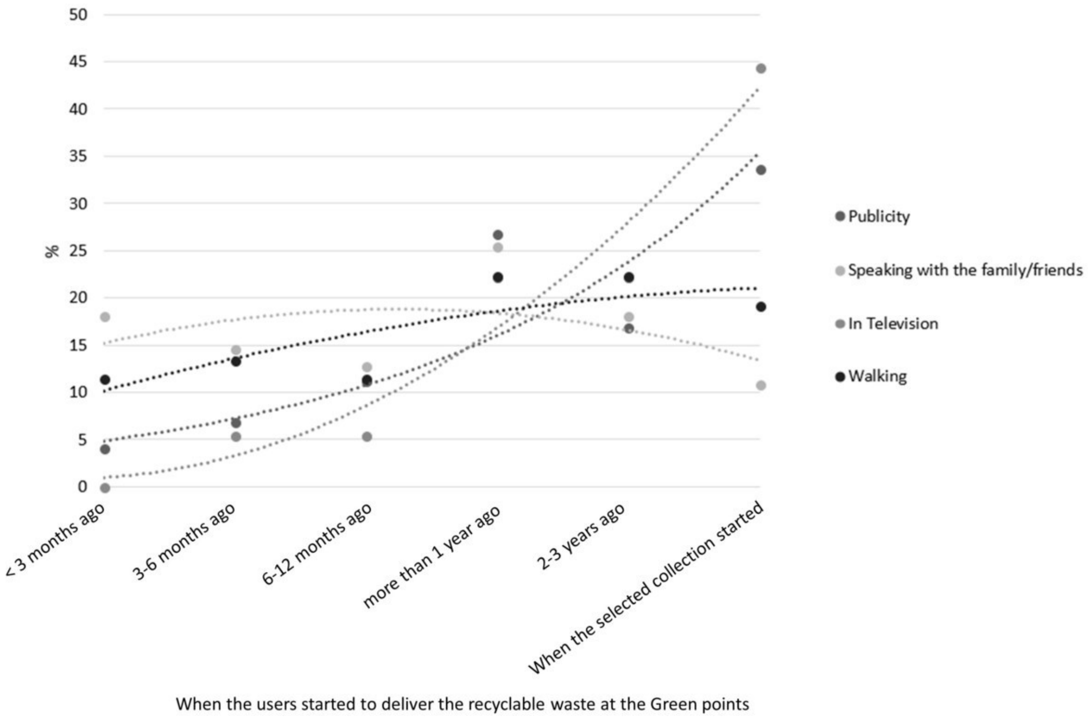


**Figure 4.5:** Relation ($\chi^2_{[40]} = 57.706$, p = 0.035) between $Q_5$ (When did you start to deliver the waste to the GP?) and $Q_6$ (How did you know the operation of the GP?).

| Basic information | Group | Population | Proportion of total (%) | CI | Sample average | |
|---|---|---|---|---|---|---|
| | | | | | Mean | SD |
| **Green points (n = 364)** | | | | | | |
| Gender | Male | 136 | 37.4 | 4.39 | | |
| | Female | 228 | 62.6 | | | |
| Age | <21 | 13 | 3.6 | 3.46 | 48.8 | 14.9 |
| | 21 - 30 | 29 | 8 | | | |
| | 31 - 40 | 73 | 20.1 | | | |
| | 41 - 50 | 85 | 23.4 | | | |
| | 51 - 60 | 74 | 20.4 | | | |
| | 61 - 70 | 69 | 19 | | | |
| | >70 | 20 | 5.5 | | | |
| People per family | 1 | 23 | 6.3 | 3.46 | 3.55 | 1.49 |
| | 2 | 66 | 18.1 | | | |
| | 3 | 91 | 25 | | | |
| | 4 | 95 | 26.1 | | | |
| | 5 | 53 | 14.6 | | | |
| | 6 | 15 | 4.1 | | | |
| | > 6 | 21 | 5.8 | | | |
| Socioeconomic status | A | 166 | 45.6 | 4.27 | | |
| | B | 74 | 20.3 | | | |
| | C | 102 | 28 | | | |
| | D | 22 | 6 | | | |
| **Neighbourhoods (n = 410)** | | | | | | |
| Gender | Male | 212 | 51.7 | 4.84 | | |
| | Female | 198 | 48.3 | | | |
| Age | <21 | 31 | 7.6 | 3.36 | 42.4 | 16.4 |
| | 21 - 30 | 82 | 20.2 | | | |
| | 31 - 40 | 87 | 21.4 | | | |
| | 41 - 50 | 93 | 22.9 | | | |
| | 51 - 60 | | 50 | 12.3 | | |
| | 61 - 70 | | 41 | 10.1 | | |
| | >70 | 22 | 5.4 | | | |
| People per family | 1 | 23 | 5.6 | 3.36 | 4.1 | 1.6 |
| | 2 | 36 | 8.8 | | | |
| | 3 | 93 | 22.7 | | | |
| | 4 | 107 | 26.1 | | | |
| | 5 | 77 | 18.8 | | | |
| | 6 | 36 | 8.8 | | | |
| | > 6 | 38 | 9.3 | | | |
| Socioeconomic status | A | 128 | 31.3 | 4.19 | | |
| | B | 89 | 21.8 | | | |
| | C | 110 | 26.9 | | | |
| | D | 82 | 20 | | | |

**Table 4.3:** Basic social information for the citizens surveyed.

At the same time, it could be noticed that the information by walking and speaking with the family/friends increased until the end of 2016, before the end of the project, and it decreased significantly in the last year, due to the reduction in public campaigns and the GP available in the city. Therefore, the result shows how the reduction in information, divulgation and availability of infrastructures, considerably influenced the involvement of the population into the formal SCS.

Considering the opinion of the users about the number of GP required for improving the SCS, results reported that 48.1% (CI 4.27) suggested introducing more GP, without considering the improvement of the collection time, or both. Summing the percentage of users that considered important the introduction of new GP and the application of the GP more days during the week, turns out that about 70% of the users need more GP. Relating this result with the one obtained for $Q_2$ (How far do you live from here?), we get that this consideration is mostly provided by the people who live farther than 1 km ($\chi^2_{[3]} = 10.611$, p = 0.014). Results are reported in Figure 4.6.

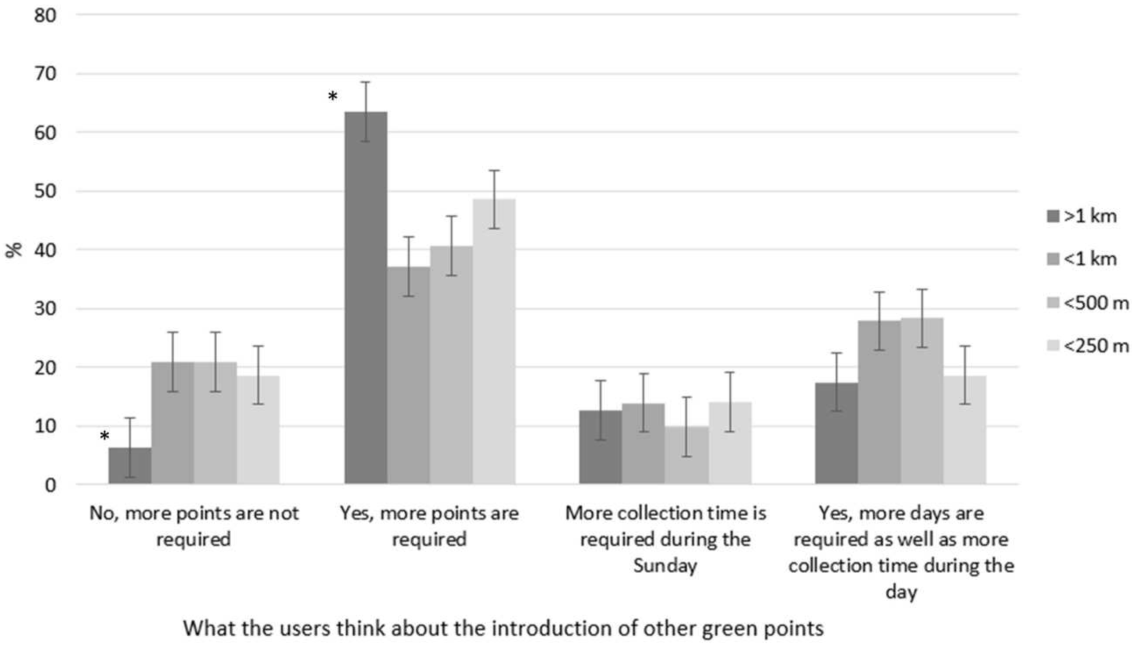


**Figure 4.6:** Relation ($\chi^2_{[3]} = 10.611$, p = 0.014) between $Q_2$ (How far do you live from here?) and $Q_7$ (In your opinion, other GP are required in the city?).
(*) Statistically significant.

Finally, results obtained for $Q_8$ (Why do you do the selective collection of the MSW?) provided the indication that the majority of the users (51.6%, CI 3.46) implement the selective collection to protect the environment and 21% to recover the material. Only 1.2% of the users do it for supporting the activity of the municipality, while 14.6% do it for personal education.

**Municipal recycling behavior**

The first three questions submitted to the citizens regard the knowledge and use of the GP. The inhabitants who know the formal SCS provided at the GP are 25.6% (CI 4.84), so the majority of the population is not aware about the presence of the recycling points of the city.

Considering the answer provided to $Q_3^N$ (Do you use the GP?) only 8% (CI 4.84) provided an affirmative answer, which is in agreement with the data available at the GP (about 2% of the population use them). Differently with the questionnaire provided to the GP, where the socioeconomic status was mostly high, in this case there is not any statistical dependence between socioeconomic level and use of the GP ($\chi^2_{[3]} = 0.06$, p > 0.9). Finally, 63.6% (CI 3.36) of the people who know the GP (25.6% of $Q_1^N$ ) stated that they knew the activity of the GP ($Q_2^N$) walking though the city during the Sunday morning, while less than 20% thanks to the publicity. These statements are according to the results obtained for the GP. Therefore, only one fourth of the population knows the GP and of them only one fifth was informed by public campaigns or advertising. The second part of the questionnaire investigates the recycling behavior of the population. Results reported that 48% (4.84 CI) of the population implement the selective collection at home. Again, there is not any statistical dependence with the socioeconomic status ($\chi^2_{[3]} = 2.48$, p = 0.48), so in contrary as expected since the majority of the people that comply with the formal SCS are of higher socioeconomic status (45.6%, CI 4.27).

Figure 4.7 reports the type of waste which is segregated by the people who implement the selective collection at home, so which answered positively to $Q_4^N$ (every interviewed could provide more than one choice). The highest percentage is obtained by the mixed plastic (22.8%, CI 2.47), followed by mixed paper and cardboard (17%) and the PEHD and PET (16.5%). Overall, 78.7% of the population who implement the selective collection at home separate plastic and paper in different method. WEEE, used batteries, organic fraction, cans and glass are not separate autonomously by the population in a widespread manner, or are produced in small quantities.

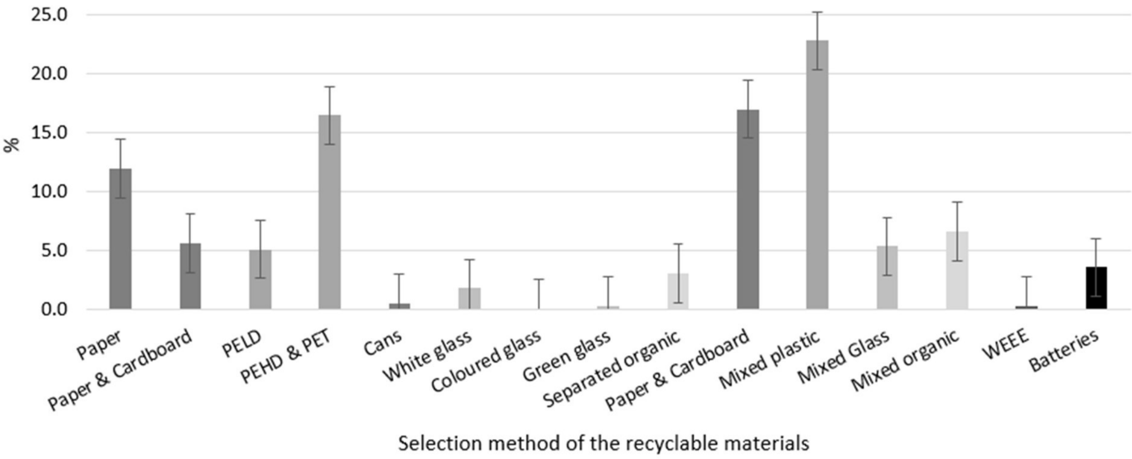


**Figure 4.7:** Answer to $Q_5^N$ - How do you separate the recyclable materials? (n = 395).

Figure 4.8 sums up the areas where the population delivered the recyclable materials sorted. The highest percentage (23.3%, CI 3.25) is obtained by the mixed containers available for the MSW collection system. It means that a significant part of the population that implement the selective collection at home, throws the selected material into the mixed waste. The motivations provided by the interviewed are two: they think that the material is then selected at the landfill; they would facilitate the work of the waste pickers who gathered the material from the bins and containers. The second answer provided is that they sell the materials to the recycling shops (21.7%), followed by "left on the road" (15.3%), where the waste pickers could collect it autonomously. In addition, 12.2% stated that they give it to the waste pickers which pass though their house (similar as a kerbside collection system), while 1.1% change it with toilet paper. Only 14.8% provide the waste always to the GP (which represent the 8% of the total sample interviewed). It means that most of the population that select the waste provide it to the informal sector or in mixed containers (73.5%).

Finally, the motivation that leads the citizens to implement the selective collection was assessed. Figure 4.9 reports the answers of $Q_7^N$. Results show that 52.3% (CI 3.64) of the population do it to protect the environment and 26.9% for recycling the material. So, 79.2% of the citizens who implement the selective collection at home, do it for environmental reasons. Only a few people stated that they wanted to earn money (less than 2%) or to support the work of the municipality (2.1%).

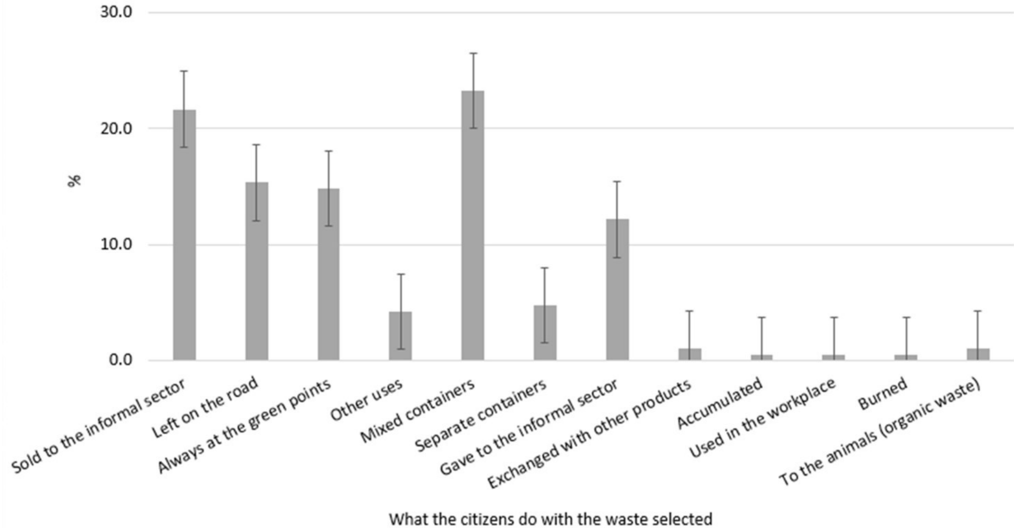


**Figure 4.8:** Answer to $Q_6^N$ - Where do you deliver the recyclable materials selected at home? (n=189).

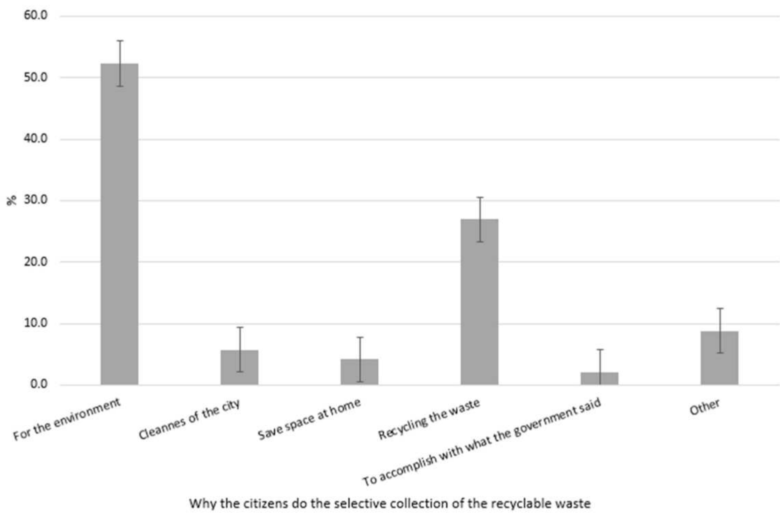


**Figure 4.9:** Answer to $Q_7^N$ - Why do you do the selective collection of the solid waste at home? (n = 193).

**Relationship between households' characteristics and implementation of formal and informal recycling**

The SC activity implemented by the citizens was expressed by two alternatives: 1 - I do; 0 - I do not implement the SC at home. Similarly, same alternatives were provided about the knowledge of the GP (1 – I know; 0 – I do not know) and for the use of the GP (1 – I use; 0 – I do not use). Binomial logistic regression was chosen for assessing the relationship between households' characteristics and recycling activity since: the dependent variables are measured on a dichotomous scale, one or more independent variables were considered, which are continuous (i.e. people per households) or categorical (i.e. male and female), and the observations are independent.

The results of the statistical analysis are reported in Table 4.4. Concerning the compliance with the waste SC, gender and people per households are the variable that influences its implementation. In particular, females are more involved in the implementation of the SC at home, in agreements with the results of the first test, where the females are the 62.6% (CI 4.93) of the users. As regard the number of members per household, results reported that more people form part the family, more they are willing to select the waste at home, especially where the members are more than four. This can be motivated by the requirements to optimize the collection of waste at home, which is proportionate with the number of components per family.

Regarding the knowledge of the GP and its use, results reported that the age of the respondents is predictor of the recycling behavior. In particular, the older interviewed are more likely to be aware of the existence of GP and its use. This agrees with the results obtained at the GP, where about 68% of the interviewed were older than 41 years. Finally, in agreement with the consideration provided by the chi-square analysis, social-economic status is never a predictor of waste SC behavior in La Paz.

| | Compliance with the SC | | | | Knowledge of the GP | | | | Use of the GP | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\beta$ | S.E. | Z | p | $\beta$ | S.E. | Z | p | $\beta$ | S.E. | Z | p |
| Gender | -0.69 | 0.21 | -3.37 | $0.001^{***}$ | -0.35 | 0.23 | -1.51 | 0.13 | -0.71 | 0.38 | -1.86 | 0.062 |
| SE | -0.05 | 0.09 | -0.56 | 0.57 | 0.1 | 0.10 | 0.96 | 0.34 | -0.01 | 0.17 | -0.04 | 0.97 |
| Age | 0.07 | 0.06 | 1.04 | 0.30 | 0.20 | 0.07 | 2.80 | $0.005^{**}$ | 0.33 | 0.12 | 2.86 | $0.004^{**}$ |
| HH | 0.16 | 0.07 | 2.38 | $0.017^{*}$ | -0.11 | 0.08 | -1.41 | 0.16 | 0.03 | 0.12 | 0.26 | 0.79 |

**Table 4.4:** SC, knowledge of the GP and use of the GP regressed on people per households, age, gender and social-economic status of the respondents (HH: people per households, SE: socioeconomic status, S.E.: standard error).
*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$

### 4.1.4 Comparison among the results of the questionnaires

Comparing the results obtained at the GP and at municipal level, the recycling behavior of the citizens can be explained considering both formal and informal SCS. The first factor analyzed (F1) regards the distance of the GP. Results underlined that the citizens that mostly used the recycling areas live not farther than 500 m. In particular, this information should be used for planning the implementation of other SC points, which should not be farther than 250 m (about 48% of households live within this distance).

The implementation of more controlled recycling points was suggested by the users of the GP, who stated that it could be more beneficial than the application of more time or more days per week ($Q_7$). This is also supported by the third factor assessed (F3), which considered the delivering time. The questionnaire demonstrated that the population mainly deliver the waste one or two times per month, although without any statistical dependence that could support this habit. As regard F2, the results demonstrated that the socioeconomic level of the people who use the GP is high. However, this is partly true, since analyzing the population behavior of the second questionnaire there is no dependence between the socioeconomic level and recycling, which could be formal or informal. Therefore, the motivation for the implementation of SCS should be search in other factors, such as political, infrastructural or promotional.

Considering the results for assessing F4 and F5, the population that use the GP is only 3-13%, while about 49% implement the SC at home, in agreement with a previous study implemented at the university, where 57% (CI 5) of the students stated to separate the waste at home [19]. Again, this behavior has not dependence with the socioeconomic status. About this 49%, more than 70% deliver the waste to the informal sector in different forms or to the mixed containers (F6). This statement is reinforced by the results provided by the people who know the presence of the GP (less than 30%) and by the media where the people sow the GP (mainly walking).

Interesting is the comparison between the results obtained with the two questionnaires. In both cases, the female gender is the one that recycle the most, suggesting that the sensitivity campaigns should be focus on this gender. Moreover, the age of the users was predictor of the use of the formal recycling system. Therefore, the youngest are not involved in the formal SCS.

### 4.1.5 Policies implications

#### A. Implementation of a pilot SCS

The results obtained allow reporting some precautions and suggestions for planning future SC strategies. The main barrier detected in La Paz for involving the population into the formal SCS is the lack of infrastructure and the lack of information, which did not support the formal SCS during the last years.

The first point for improving the formal SCS is to inform the population about the presence of formal recycling activities, involving the youngest, since are the low informed of the system. Sensitivity campaigns, publicity and social activities at schools and universities are compulsory for improving the awareness of the population [20], as well as educational materials which target moral obligation and action planning [21].

The second point for improving the formal SCS is the introduction of infrastructures. As reported by other authors, the implementation of any activity aimed at increasing involvement in waste separation, could be a waste of time and money if recycling facilities are not implemented [22]. This recommendation was converted in an action plan within the municipality, that started the implementation of a new pilot SCS at the end of 2018, introducing separate street containers in two areas of the city (Figure 4.10). The good starting point that justified this plan is that about 48% of the population implemented the SC at home, although in different methods. Knowing that only 25% of the population knows the activity of the GP, the information system was boosted involving the other part of the population which do not implement it autonomously.

It should be highlighted that the results of the social survey reported that the recycling behavior is not influenced by the socioeconomic status, although it is not true for the formal SCS. It can be motivated by the fact that recycling is a dynamic process that is influenced by personal and environmental factors [23] and the formal SCS was not supported by sufficient information campaigns. This represents another good point that was considered by the local stakeholders since the introduction of recycling policies can be direct to the whole population, diversifying the SC methods considering the districts where the informal sector is just present and the geographical conformation of the area. Anyhow, in agreement with the results of the questionnaire survey, the pilot system was implemented in the richest neighborhoods and the ones where the SCS by GP obtained the highest RR, in order to obtain immediate good results and justify the implementation of the SSC.

**Figure 4.10:** Separate containers implemented in two districts of La Paz in 2018

### B. Inclusion of the informal sector

As also reporte within the second chapter of the thesis, the informal sector can be considered an ally of the formal SCS, since a relevant part of the global population deliver the waste to waste pickers and recycling shops, deviating the streams inflow into the landfill reducing the MSW management costs. This is common in Latin America: in Santiago de Chile, Chile, informal collectors transport the waste to an intermediate collector or sell it directly to recycling companies and, at national level, they contribute approximately 86% of the total waste that is recycled [24]; In Sorocaba, Brazil, autonomous pickers increase the recycling rate of the city to 9%, with benefits both for the pickers and the municipality through savings on landfill costs [25].

In La Paz, the inclusion of the informal sector can be beneficial for the government, since it is just recognized by the population and can reduce the expenses for the introduction of new GP or SSC. This assumption was considered by the local government, that started information campaigns and activities for supporting the waste pickers in a few neighborhoods of the city.

The plan for including the waste pickers was introduced by the aid of the volunteers of the University, who helped the implementation of the questionnaire survey, the representatives of the citizens and the waste pickers (Figure 4.11). The inhabitants of a district were informed about the presence of a family that collected the recyclable waste within the neighborhood and that three days per week was available for collecting the waste in the square. The information campaigns were implemented delivering door to door information sheets to the citizens, explaining directly the benefits of the service and of the practice. Therefore, the introduction of formal SCS is not the only choice for improving the recycling rate in La Paz.

In Managua, Nicaragua, hundreds of waste pickers were displaced after the “safety management” project of its open dump site. Employment benefits from the project were distributed by neighborhood, and informal waste pickers suffers due to continued social and economic marginalization [84]. This represent a clear example of what the implementation of new MSW management plans can generate without considering the presence of the informal recycling, which should be translate in income for low-income households. This is not happening in La Paz, since the local government is considering this practice and the will is to improve its activity for introducing mutual environmental, economic and social benefits, considering the requirement of a resilient and integrated MSW management system.

**Figure 4.11:** Support activity to the waste pickers operating in La Paz in cooperation with the volunteers of the university, GAMLP and citizens.

The practice of the informal sector should be considered also for planning waste treatment facilities. The informal collection of recyclable waste means reduction in waste amounts to the material recovery facilities or reduction of the calorific value of the waste. Therefore, it should be considered the reduction of the financial sustainability of the plant, or its wrong dimensioning with higher investment costs. Moreover, the implementation of SCS by kerbside or SSC collection, should be implemented in areas where the informal sector does not operate, in order to save investment and collection costs, reinforcing the activity of the waste pickers.

#### C. New infrastructures implemented for the formal SCS of La Paz

After the implementation of the questionnaire survey, a pilot project for improving the RR of the city was introduced in two neighborhoods of the city, as reported in previous subsections. Blu and yellow separates containers were located at about 250 m meters to each collection point, for collecting paper & cardboard and plastic waste (PET, PELD, PEHD, PP), respectively. Moreover, fixed GP were implemented for collecting metal (ferrous and non-ferrous), batteries, WEEE and glass. The containers were located by the private company that carried on the waste collection at municipal level (La Paz Limpia - LPL), since in 2017 signed a contract that forecasted the implementation of SCS.

The SC of paper & cardboard and plastic was justified by the social survey, since the people mostly collected these fractions, and by the fact that the market accept them. Therefore, the SCS was implemented for covering about 56,218 inhabitants (about 6.2% of La Paz inhabitants). The neighborhoods where the SSC were located are of high income, with a generation of waste per capita of about $0.691kg\,d^{-1}$ [27], for a total generation of about $38,848\,kg\,d^{-1}$ and $271,934\,kg\,week^{-1}$. The percentage of plastic, paper and glass generated are about $13.76\%_{wt.}$ (excluding PVC, PS, ABS and PC), $12.8\%_{wt.}$ and $2.6\%_{wt.}$ [27].

The quantities collected by the SCS were measured at the material recovery facility of the city, in parallel with the selection yield obtained per waste fraction. The amounts of plastic, paper and glass selected per week during the first three months are reported in Figure 4.12. These amounts are the total available within the separate containers. However, the selection yield was of about 62%, 65% and 97% for plastic, paper and glass respectively. Therefore, the amount used for recycling are less than the ones collected, as usual by this collection method. The amount of waste available within the neighborhoods, the ones collected, and the net recovery rate obtained by the SCS are reported in Table 4.5. Results are encouraging since, although as pilot plan and with a reduced number of SSC available, the waste separated can be satisfactory. As advised before, information campaigns are compulsory for improving the waste selection rate, as well as the analysis of the activity of the informal sector.

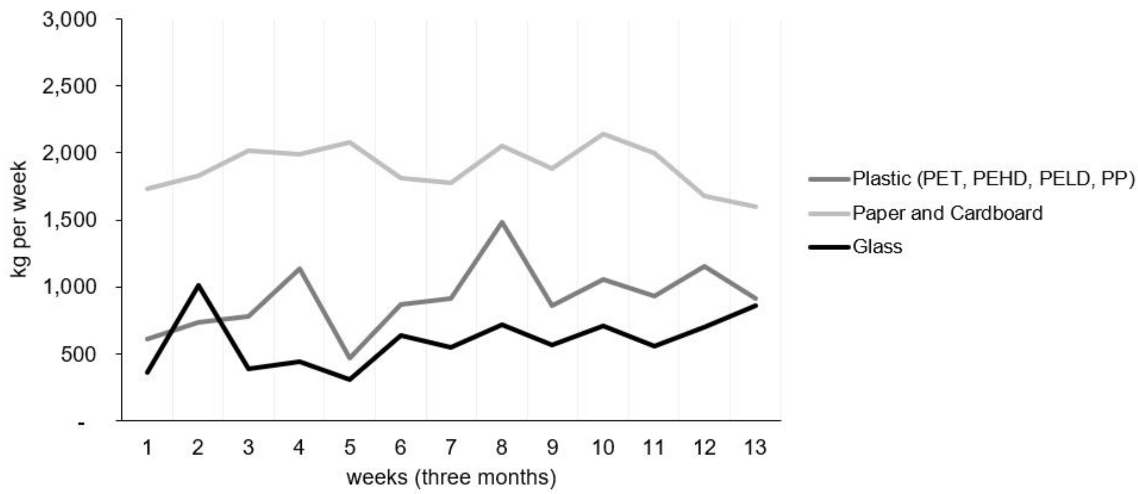


**Figure 4.12:** Amount of waste collected by the formal SCS with the pilot project with SSC during the first three months of operation (September, October, November 2018)

These fractions are the most collected in Latin America and low-middle income countries since they provide more chances of incomes. In Brazil, the recycling chain of paper and plastic is supported at national level, and it is manly introduced by the informal recycling, organized in associations and cooperatives [28]. In São Leopoldo, Brazil, pre-segregation of recyclable materials is implemented, both formal and informal. However, the implementation of advanced treatments is still not implemented like in high-income countries, since these treatments also generate costs, mostly recovered from residents who pay annual fees [29]; financial sustainability still represents a barrier in Latin America, where the MSW management system is still subsidized by the

Governments. Waste-to-energy technologies should be also considered for improving waste recovery of other fractions in Latin America, closing the loop of waste. Again, these projects should receive additional incomes, especially from gate fees that should be pay by the users, and benefits from special tax deductions [30]. Therefore, improvements should be still implemented, focusing in improving local know-how, data collection, informal sector inclusion, financial sustainability and population sensitization.

| Waste fraction | $\%wt.$ of waste fraction | $kg\,week^{-1}$ produced | $kg\,week^{-1}$ recovered | % recovered |
|---|---|---|---|---|
| Plastic | 13.76 | 37,418 | 568 | 1.52 |
| Paper & cardboard | 12.8 | 34,808 | 1,237 | 3.55 |
| Glass | 2.6 | 7,070 | 584 | 8.26 |

**Table 4.5:** Waste recovery rate within the two neighbours were the SCS with separate containers was introduced at pilot scale.

### 4.1.6 Remarks and considerations

The research demonstrates how the implementation of social survey at city level can be considered a decisional tool for introducing new SCS and recycling plans, considering local needs and the recycling activities just in place. In particular, the presence of the formal SCS system should be make known among the citizens, as well as the informal one.

Recommendation of the study is to do not generalize the social behavior with other cities or countries since every context has its economic, social and environmental characteristics. The study demonstrated how the inclusion of the informal sector is just supported by the citizens and should be only reinforced with municipal campaigns and specific regulations that should be discussed directly with the waste pickers.

The analysis also reported how, also in low-middle income developing cities, the implementation of SCS can be considered feasible, although inclusion of the population, data analysis and implementation of pilot plans is required for introducing a step by step and integrated system. The examples provided can be as reference for other big cities worldwide.

For improving the SWM system of the city, a range of information will be needed before implementing a SCS at city level. Survey data such as the one presented in this study is a part of required information. A cost–benefit analysis is also needed to assess the feasibility of a big-scale recycling program, considering the activity of the waste pickers and recycling shops.

The survey reported that the informal sector can be considered an alley for improving the RR of the city. La Paz can be considered as a good example for implementing recycling policies in low-middle income countries since the population just supports the SCS, mainly for environmental reasons, the informal sector is just included, also in national laws, and the local government is aware about environmental, technical and social requirements. Although circular economy could be considered a challenge for low-middle income countries, this study demonstrated that the population can be ready for implementing waste separation strategies, supporting economic, environmental and social sustainability at global level.

Other analysis should be included. In particular, an environmental impact assessment of future scenarios, for assessing its sustainability, and spatial analysis by GIS, in order to choose the best districts for implementing SCS by SSC or DtD collection. Moreover, the inclusion of students and children is compulsory, since represent the less involved part of the population. For these reasons, the next chapter are focused on the integrated analysis of these factors, in order to improve the analysis for introducing and integrated approach for choosing the best SC plan.

## 4.2 LCA of SWM future scenarios: Application of the software WRATE

This research refers to the article *" Application of LCA for assessing municipal solid waste management systems in Bolivia "* (Ferronato N.,Gorritty Portillo M.G., Guisbert Lizarazu E.G. and Torretta V.) submitted to the *Waste Management & Research* Journal and currently under review (re-submission).

### 4.2.1 Introduction

LCA is an approach used for planning MSWM systems. It is used in order to identify options that prevent or minimize negative environmental impacts [31], to analyze strategies for material and energy recovery from waste [32] and to compare the total potential impacts of the technologies available for waste valorization [33].

The application of LCA for planning MSW collection and treatment, with the aid of LCA software, is mostly conducted in high-income countries [34]. This is due to the high technical expertise required, knowledge about the existence of this management tool, and the cost for affording the use of LCA software, necessary for implementing complete LCA studies. Moreover, models developed in different countries rely on geographic data that influence the results of waste LCA models [35]; impacts database are not always suited for such geographic specifications, affecting the reliability of results in countries where data consistency is low. However, the LCA approach should be also encouraged in low-middle income countries, where the implementation of sustainable SWM actions is mostly required for reducing global environmental impacts, such as marine littering, open burning, and open dumping, typical of these contexts.

LCA software and impacts database are compulsory for implementing reliable LCA. Annual full software licensing is sometimes available free of charge for no-OECD (Organization for Economic Cooperation and Development) countries, but for limited periods. At the same time, academic licensing is making available for longer periods but only for scholars and researchers, making parts of databases or software accessible with limited functionalities or providing discounts to licensing fees. The implementation of LCA approaches is therefore challenging in low middle-income developing cities, due to the deficiency of data accessibility, the absence of specific database available into the LCA software (i.e. the impacts due to open dumping), the lack of knowledge and the lack of economic sustainability for using full licensing LCA software. The research presented in this paper discusses these issues, implementing an LCA of the MSWM system of La Paz (Bolivia) using the academic license of the LCA software WRATE (Waste and Resources Assessment Tool for the Environment), free of charge and available only for scholars and researchers. The research would demonstrate the potentiality of the applicability of academic licensing for implementing preliminary assessment of MSWM systems, as first step for improving awareness and know-how to stakeholders of low-middle income countries, in cooperation with local partners.

The study was conducted in La Paz in cooperation with the Major University of San Andrés and the local Government of La Paz, collecting some information required for the LCA and presenting the main results obtained to the local engineers and stakeholders. The objective of the research is to provide evidence of the potentiality of an LCA implemented with academic licensing, explaining the importance of national and international cooperation between the academy and policy-makers for improving know-how and capacity building in low-middle income countries for finding international economic funds. In particular, the novelty of the study is to discuss the potentialities of preliminary MSWM LCA in developing cities for submitting international cooperation projects for supporting sustainable development. The case study presented underlined the opportunity to start a project financed by the Italian Agency for Development Cooperation (AICS) in collaboration with local stakeholders, using the LCA as technical approach for evaluating the environmental benefits of the collection and treatment improvements obtained thanks to the MSWM project.

The study presents the results of the LCA of the MSWM system of La Paz, where the current one (in 2018) is compared with future MSWM scenarios. At the same time, the potentiality of such preliminary results is discussed, focusing on the importance of explaining to local stakeholders the importance of the approach. The results allow introducing a preliminary ranking of the management scenarios available for implementing advanced MSW collection, treatment, and final disposal systems. The outcomes are comparable with other analysis conducted in similar areas of the world with full licensing software. Therefore, the article comments the requirements for guarantying and spreading affordable management tools in the developing world for improving environmental knowledge and awareness at global level.

### 4.2.2 Methods

#### Life cycle assessment

The study was conducted according to ISO 14040 standards. Therefore, the research is divided in four parts: (Stage I) goal and scope definition, which contains the goal of the research, the functional unit, system boundaries, the users of the results, limitations, and the list of environmental impact assessed; (Stage II) life cycle inventory (LCI), preceded by the description of the scenarios; (Stage III) the life cycle impact assessment (LCIA); and (Stage IV) interpretation of the results, where the sensitivity analysis is implemented [36].

#### Stage I: Goal and scope definition

The goal of the LCA is to compare the existing MSWM system with other alternatives in terms of environmental impacts for choosing the best environmental options. The functional unit is the annual generation of MSW, approximately equal to $229,207\,t$ generated in 2018, with the hypothesis that the MSW generation was similar with 2016. The system boundaries consider the generation, storage, collection, transportation, treatment and final disposal of MSW, as well as recycling (Figure 4.13). Open loop recycling and the utilization of the electricity produced outside the boundaries of the system are considered, avoiding allocation issues (i.e. use electricity as by-product of the MSWM).

For the study, data for the LCI was gathered from local documentation, field inspections to the sanitary landfill and facilities of the city and from interviews to local engineers and experts in the field of SWM. When not available, some processes and plans were introduced from the software database, while some assumptions were made: the amount of waste that is not gathered by the formal and informal system is hypothesized to be about 1-5% of the total generated at municipal level.

**Software used for modelling and life cycle impact assessment**

The database from the WRATE software academic version 3.0.1.7 developed by Golder Associates (2007-2014) were used for the research. Four impact categories were investigated with the method recommended by the institute of the Faculty of Science of Leiden University (CML 2001): Global warming potential (GWP) ($kg\,CO_2-eq$), Eutrophication potential (EP) ($kg\,PO_4^{3-}-eq$), Acidification potential (AP) ($kg\,SO_2-eq$), and human toxicity potential (HTP) ($kg\,1,4-DCB-eq$). Moreover, MSW streams values were assessed, in terms of MSW recycled, MSW landfilled and biodegradable waste dumped in control sites. The impact assessment includes characterization and normalization methods.

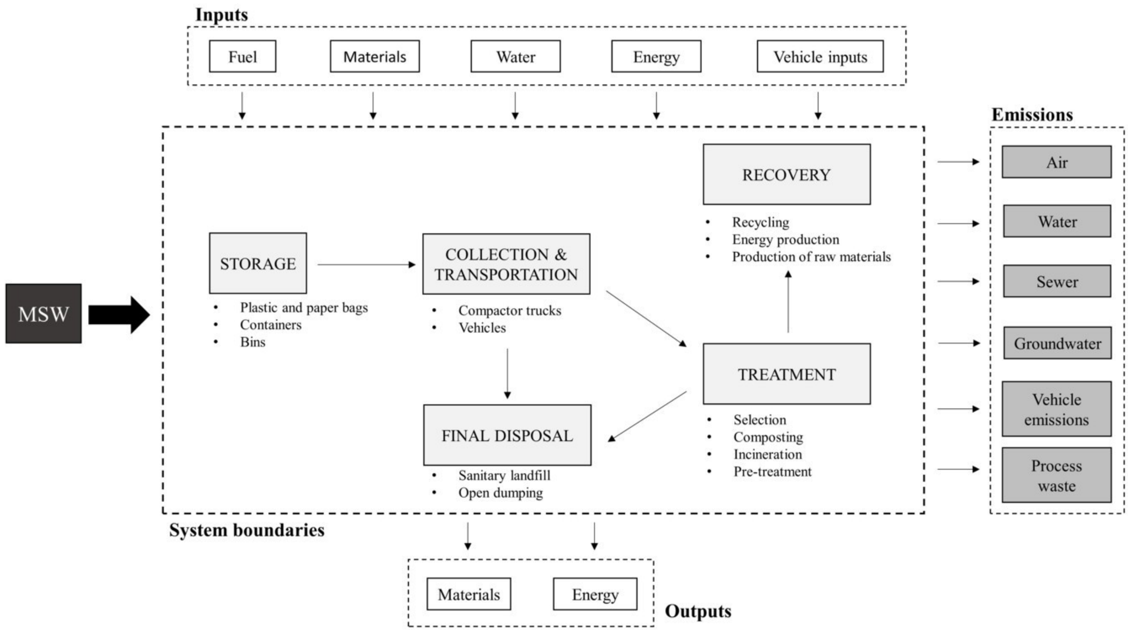


**Figure 4.13:** System Boundaries of the LCA conducted in La Paz

**Limitations of the academic licensing**

The academic version of the software WRATE does not allow making extreme modification of parameters and internal database, limiting the quality of the analysis. First of all, it is not possible to modifying the MSWM facilities with local parameters and characteristics. Therefore, the ones available in the internal database of the software were used. Data about the waste fraction and the amount of waste managed in the plant were introduced according to the data collected locally, as well as data about the type of routes, the distances traveled by the collection trucks, and the capacities of the treatment plants. Secondly, the energy mix implemented for the analyses cannot be modified with the Bolivian rates. Therefore, medium carbon emission electricity mix were used, according to the data available in the software database. Finally, the parameters of the processes for recycling cannot be modified. Therefore, the MSW recycling was adapted in function of the database of the software.

**MSWM scenarios**

Excluding the current MSWM system, seven scenarios were considered for the analysis. The first six are possible scenarios reliable for the case study and previously assessed with other methods (Section 3.2). The last was added as long-term theoretical scenario, considered as high-technological MSWM option achievable with advanced treatment plants, know-how and financial support (section 3.1.3).

Scenario 0 (S0): It is the MSWM baselines and current scenario, where landfilling, informal recycling and SC pilot plans are the main MSWM activities implemented at municipal level. The MFA is reported in Figure 4.14. About $550\,t$ of MSW are disposed per day, while $1.5\,t$ of recyclable waste are gathered from SSC, schools and green points with yellow plastic bags, and recycled at national industries. The informal sector collects about $40\,t$ of waste per day, mainly plastic, glass, paper and metals. The recycling activities introduced by the informal sector and by the formal activities allow achieving about 8% of SC. Finally, about $4\,t$ of OFMSW, collected from gardens, parks and markets, are collected and composted, and the compost is used for landfill reclamation. About 2% of the total MSW produced at municipal level is considered to be bumped in open areas or rivers. This scenario is considered as baseline of every scenario assessed by the LCA.

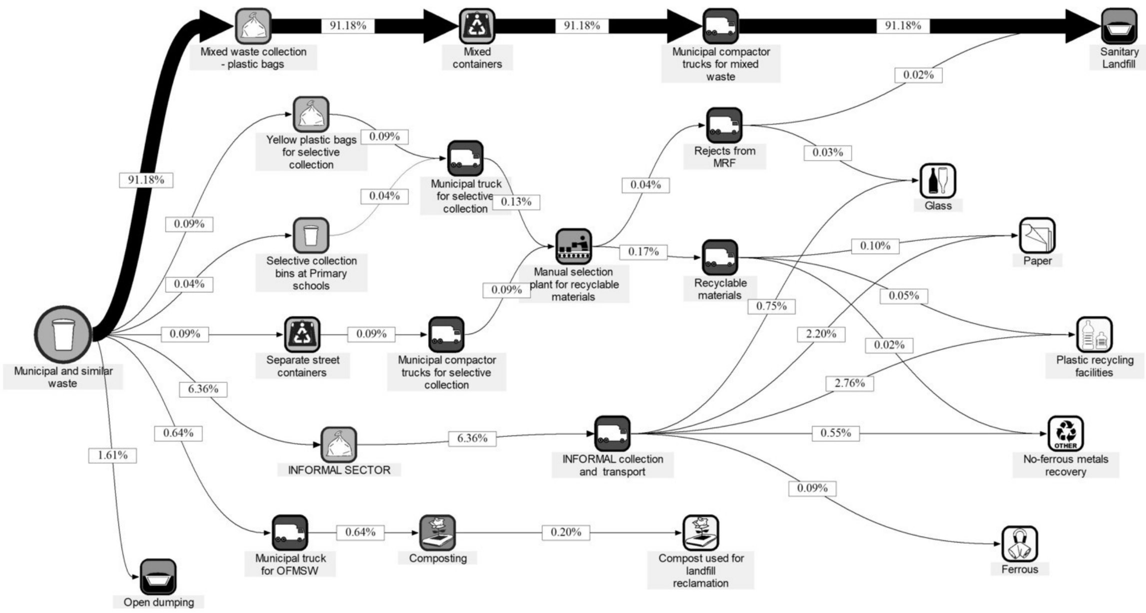


**Figure 4.14:** Waste flow analysis of the baseline scenario (S0) expressed in percentage (functional unit: 229,207 tons per year – graph obtained by the software WRATE).

Scenario 1 (S1): In this scenario the SC is improved by the introduction of SSC of paper, plastic, glass, metal and the organic fraction. Therefore, compared to S0, this scenario introduced SSC for organic waste and higher SC rates. The SC rate considered is of about 50% of plastic, 50% of glass and 50% of metals, as maximum SC rate achievable by SSC in big cities. At the same time, 25% of OFMSW SC was considered, for obtaining a recovery rate of about 3-5%. At the same time, the MRF of the city and big scale composting facilities are considered to be introduced. The compost produced cannot be considered totally of high quality, so it is also recovered as landfill cover material.

Scenario 2 (S2): The scenario foresees the DtD collection of the OFMSW and mechanical selection of recyclable materials before landfilling in a MRF for dirty materials. The MRF before landfilling is introduced for selecting the plastic, glass and metal fractions available within the mixed MSW, with a recovery rate of about 25% recyclable plastics, 75% of recyclable glass and 95% metals available in the MSW inflow into the plant. The compost produced after the DtD collection and composting is used as fertilizer.

Scenario 3 (S3): The third scenario involved the inclusion of the IS, for improving the RR of the city, and the implementation of a MBT before landfilling. The aim of the scenario is to take advantage of the current recycling activity just in place in the city with public campaigns and social policies. This improvement allows increasing the SC of about 80% of non-ferrous metals (i.e. copper and aluminium cans), about 50% of ferrous metals, about 30% of glass, about 35% of dense plastic and about 35% of paper and cardboard. At the same time, the introduction of an aerobic MBT before landfilling reduces the impacts due to the organic fractions inflow into the landfill and allows the recovery of a few amounts of recyclable waste inflow into the plant: about 16% of glass and 86% of metals. The rejects that can be converted in RDF are disposed to the sanitary landfill, as well as the stabilized waste.

Scenario 4 (S4): The DtD collection with paper bags of the OFMSW, treated by composting, and the introduction of SSC of recyclable waste are implemented in S4. The aim of this scenario is to improve considerably the formal RR of the city, improving the quality of the material recovered. It is an improvement of S1, where the collection of the OFMSW by SSC does not allow the production of high-quality compost. The SSC allows intercepting about 45% of paper and cardboard, about 25% of plastic, about 50% of glass, and 35% of metals, while the DtD collection 80% of OFMSW.

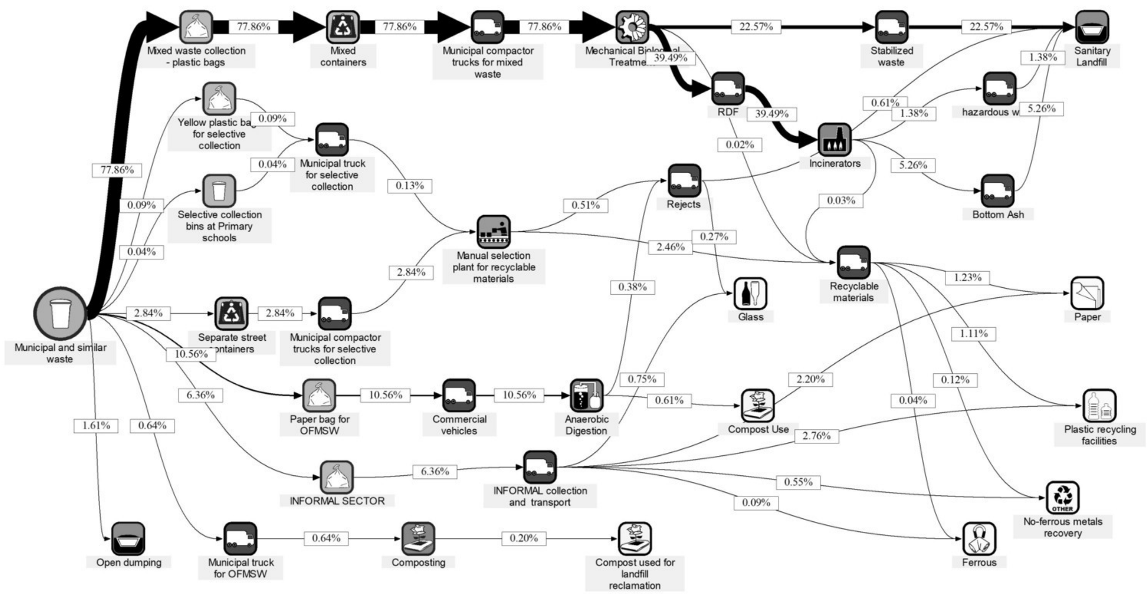


**Figure 4.15:** Waste flow analysis of S7 expressed in percentage (functional unit: 229,207 tons per year – graph obtained by the software WRATE).

Scenario 5 (S5): The fifth scenario comprehend the inclusion of the informal recycling of inorganic waste and the DtD collection of the OFMSW. If compared with S3, the improvement consists in the implementation of the DtD-SC of the OFMSW, for recovering the organic fraction. The informal sector collects about 35% of paper and plastic, 50% of metals and 30% of glass, while the organic fraction collected is about 80% of the total generated at the municipality.

Scenario 6 (S6): The MSWM options considered for this scenario are the SC of recyclable fractions by SSC and MBT before landfilling for recycling inorganic MSW and reducing the impacts of the OFMSW at the sanitary landfill. The SSC are located for the collection of plastic, glass, and paper, as also suggested in S1 and S4. As implemented in S3, an MBT is proposed to be located before the sanitary landfill, in order to recover metals, plastic and glass, and for reducing the environmental impacts due to OFMSW disposal.

Scenario 7 (S7): The last scenario describes the implementation of an MBT as pre-treatment before landfilling and energy recovery with incineration plant. Moreover, the OFMSW collected selectively by the DtD system is treated in an AD plant for the recovery of electricity, while the recyclable waste is collected by SSC. It is estimated that about 10% of SC of recyclable waste (plastic, paper and metals) and 20% of OFMSW is collected by the system. The aim of the scenario is focused on the energy recovery with the incineration plant and the integrated implementation of the collection and treatment option for all the fractions available in the MSW. This scenario is depicted in Figure 4.15.

**Stage II: Life cycle inventory**

Within the LCI, the processes and systems are described in function of the treatment and collection options used. The analysis involves data collection to quantify relevant input and output for the different scenarios evaluated. Several processes are considered for different waste streams after storage and collection. The functional unit is assumed to be constant for all the scenarios assessed, as well as the physical characteristics and its composition (Table 4.6). The values about MSW fractions represent the data obtained in a study conducted in 2008 in La Paz (the most recent available) while the physical components are obtained by the database of the software WRATE, which provided general standards in function of the waste input. Waste of electrical and electronic equipment, construction and demolition waste, used batteries, tires, furniture, and hazardous MSW were not included in the LCA. The LCI of the storage, collection, treatment, recycling and final disposal is obtained by the database of the software WRATE, including energy (electricity and heat) and fuel consumption, avoided manufacture of recycling materials (paper/cardboard, plastics, glass, metals) and avoided energy consumption.

**Storage**. The first component of the MSWM system is the storage system. Bins, containers and bags are introduced in the LCA for assessing the storage stage. Plastic bags are used for collecting mixed and selective MSW. They are typical black plastic bin bags made from 80% virgin LDPE and 20% HDPE. The scope excludes transport and packaging required to deliver the product to the market. The max capacity is of $23.4\,kg$, while the bag mass (empty) is of $0.028\,kg$. For estimating the maximum capacity, a bulk density of $0.26\,kg\,l^{-1}$ for mixed MSW was used. Mixed and separate MSW are collected in $2.5\,m^3$ steel street containers with annual maintenance, typically used for municipal collection. The life span is of about 15 years, with a max capacity of $650\,kg$, and a weight of about $140\,kg$ (empty). Finally, SC wheeled bins are used in schools and other big generators for collecting paper, cardboard and plastic. They are

| Waste fraction | % | Physical characteristics | |
|---|---|---|---|
| Paper and Cardboard | 12.77 | Net calorific value | $8.53 MJ\, kg^{-1}$ |
| Plastic film | 3.19 | Moisture content | 42.63 % |
| Dense plastic | 11.88 | Ash content | 12.79% |
| Textiles | 1.25 | Carbon | 23.91% |
| Wood | 0.48 | Chlorine | 1.04% |
| Fine materials | 3.58 | Hydrogen | 3.28% |
| Glass | 2.63 | Nitrogen | 0.92% |
| Organic | 52.82 | Sodium | 0.54% |
| Ferrous metals | 0.19 | Sulphur | 0.13% |
| Non-ferrous metals | 1.27 | Potassium | 0.34% |
| Combustible fractions (non-recyclable) | 9.24 | | |
| Non-combustible fraction (non-recyclable) | 0.70 | | |

**Table 4.6:** Waste fractions [27] and main physical characteristics (WRATE database).

composed of virgin steel, virgin HDPE, rubber, carbon black and recycled HDPE. The wheeled bins have a capacity of $240\, L$, manufactured in three parts: the main container body, the lid and the wheels. Lifespan on the product is dependent on its use and it is estimated to be around 17 years. The max capacity is of $62.4\, kg$, with the mass of the bin of about $17.2\, kg$ (empty).

**Collection**. Two type of vehicles are considered for transporting the waste: Compactor trucks, used by the formal municipal collection system, and curbside medium goods vehicle (caged), hypothesized to be used by the informal collection. The compactor trucks are collection vehicle with diesel fuel. The body is a $23\, m^3$ single compartment with compaction equipment, mainly composed of welded mild steel. The main component of the engine is also steel. The lifespan is typical of a of commercial vehicle: 7 years cycle or $250,000\, km$. The vehicle mass is of about $13.2\, t$, with a max capacity of $12.8\, t$. The distances traveled for the MSW SC are of about 40km, of which 80% in urban areas, 10% in rural areas and 10% in motorway. For the collection of OFMSW at markets and parks it is assumed to be 100% in urban areas, and to travel about 20km per trip, while the collection of mixed waste is assumed to be implemented for 90% in urban areas, 5% in rural areas and 5% motorway. The informal collection is hypothesized to be implemented by medium goods vehicle (caged) of $7.5t$ . It is a typical curbside collection vehicle with cage for collection of dry recyclables. The lifespan is of 7 years cycle or $250,000\, km$, with max capacity of $2.7\, t$ or $9.8\, m^3$. The distances traveled are assumed to be $40\, km$, 80% urban, 10% rural and 10% motorway.

Three other types of trucks are considered for transporting the products (recyclable raw materials, compost, RDF and rejects): Medium goods vehicles ($3.5 - 7.5\, t$) with max capacity of $2.4\, t$ or $4\, m^3$ are used for the transportation of rejects from the MRF to the sanitary landfill. The vehicle mass is of about $4.5\, t$, with lifespan of $500,000\, km$. The distances traveled are $5\, km$, 100% in rural areas. Similar medium goods vehicle ($7.5 - 17\, t$) are used for the transportation of recyclable waste materials to recycle plants. The travel comprehends 100km of which 40% urban, 10% rural and 50% motorway. Finally, intermodal road transport is assumed to be used for rejects, glass and RDF produced after MBT. The max capacity is of $17.6\, t$ or $67\, m^3$, with the vehicle mass $13.7\, t$ (empty) and lifespan $500,000\, km$. Vehicle and container construction, maintenance (per $10,000\, km$), and fleet emissions per 100km are considered for evaluating the impacts. The distances traveled are of about 10km from MBT or incineration plant to sanitary landfill of which 33% urban, 33% rural and 34% motorway. Moreover, 10km with 80% urban, 10% rural and 10% motorway are traveled for the transportation of recyclable glass or rejects from MRF to sanitary landfill or recycling plants.

**MSW Treatment technologies**. The MSW produced in La Paz is assumed to be treated and recovered in MRF, composting plant, AD plant, incineration plant, depending on the scenario considered, and finally disposed of in a controlled sanitary landfill. These treatment plants are not available in La Paz, but they are used for the LCA in order to estimate the environmental impacts of the MSWM systems.

The recycling materials collected separately are assumed to be treated in a semi-mechanized MRF with infrared plastics separation. The MRF is composed of a bag splitter and conveyor belts, allowing the primary manual sorting for removing plastic sacks, textiles, cardboard and any large items of waste. The waste is then conveyed to the trommel screen designed to remove small items of material. A ballistic separator separates the light pieces of paper and plastic, sorting automatically HDPE and PET using Infrared technology. Steel cans are removed from the conveyor using overbend magnets. Finally, a manual check of the quality of the materials and sort plastic bottles and paper is implemented. The materials are then baled into blocks, wrapped in wire to be stored and transported to the recycling plants. The MRF can achieve 90-95% efficiency in material capture for recovery with a maximum capacity of about 50,000t per year.

The OFMSW collected by DtD collection from households, markets and parks is assumed to be treated in composting plants. The treatment is implemented in a modular composting system for source segregated OFMSW. The working principle is to force air into a compost windrow and to control temperature and emissions by a combination of controlled air supply and exhaust air filtration. Mixed material is aerated for 14-21 days in the stage 1 tunnels where it achieves a minimum temperature of 60ºC for a minimum of 48 continuous hours. The tunnel is a 21m x 6.5m concrete floored and walled structure. After 21 days the semi-treated material is removed from the stage 1 tunnels, turned and placed in the stage 2 tunnels. It is aerated for a further 14-21 days again achieving a minimum temperature of 60ºC. The material will be 100% sanitized and 70% stabilized at the end of this stage. The stage 2 tunnels are emptied, and the material is delivered to the maturation area. It is made up into a windrow and turned weekly over an eight-week (56 days) period. At the end of this maturation phase, the compost is inactive, very low in odor and dry enough to screen successfully. The matured material is removed from the maturation pad and screened to 10mm or 30mm. The oversize fraction is sorted to remove the plastic, while the compost is removed from site for use as landscape products, restoration material or for use in agriculture. The plant has 15-year lifespan, covering 2ha of land take, with 30,000t of maximum annual capacity.

As other option, the OFMSW is treated in a small-scale automated AD facility for energy generation and digestate production. The waste is shredded for reducing particle size to less than 20mm and transferred to a conditioning tank in order to homogenize the waste and to further reduce particle size to less than 5mm using a secondary shredder. The waste is then transferred to the digestion tank with a capacity of $800\,m^3$. The hydraulic retention time is of 20 days, with organic loading rate equal to $4\,kg\,m^{-3}d^{-1}$ with mesophilic temperature equal to 37°C. Digestate is transferred to a pasteurization tank with a capacity of $20\,m^3$. The pasteurization process is a batch process which takes place on a 6-hour cycle heated to 71°C. Biogas is piped from the roof of the digester tank, pasteurization tank and digestate storage tank to a single gas holder with capacity of $200\,m^3$. The biogas is used in a single combined heat and power unit with an electrical output of 250kW and a standby dual fuel boiler producing electricity and hot water. The lifespan is of approximatively 15 years, with maximum process capacity of $75,000\,t$.

The mixed waste before landfilled can be pre-treated by an MBT with aerobic bio-stabilization in composting tunnels. The plant considered within the analysis foresee a mechanical separation in two lines, where the waste is shredded, and the metals are recovered using overbend magnets. The material is then fed to a screening drum where the high caloric material is separated. The smaller material is composted for 4 weeks, screened and transported to the sanitary landfill where a further biological treatment of about 8 to 10 weeks will be carried out in open windrows. The middle caloric material is separated for further use/combustion. The total residence time of the waste is of approximately 84 days. The lifespan of the plant is assumed to be 20 years, with an annual capacity of about $75,000\,t$.

The last treatment technology considered is incineration for energy generation. The plant has a design capacity of $7\,t$ per hour, equal to $56,000\,t\,y^{-1}$. The heat produced is used to generate electricity for export to the national grid and hot water for export. The process generates approximately 3MW of electricity. The combustor is a conical oscillating kiln. Bottom ash from the end of the kiln is discharged into a water filled quench pit. Bottom ash and residues are sent for disposal or recovery, while ferrous metals are sent for recovery. All other solid waste residues arising from the operation of the process are removed from site for disposal. The incineration gas is treated with powdered lime and activated carbon to neutralize acid gases and absorb (primarily) dioxins/furans, dioxin like PCB, volatile organic compounds and mercury. Bag filters remove the fine ash, excess lime and carbon as the gases pass across the bag fabric. NOx reduction is by SNCR using urea which is injected into the combustion chamber. The oxygen concentration and temperature above 850°C are carefully controlled to minimize dioxin emissions. The cleaned gas then discharges to atmosphere via one 55-metre stack.

**Final disposal**. Mixed MSW and rejects are disposed of in a sanitary landfill with flare only of landfill gas, basic liner of HDPE, and daily cap of clay. It is estimated that 20% of landfill gas collection rate is obtained by the collection system. The maximum annual capacity is of $250,000\,t$, with a lifespan 20 years and 12.5 ha of land take. MSW is deposited daily in the site and compacted with a compactor used on the operational areas to level the waste. The landfill leachate is treated in order to reduce its load of contaminants in a leachate treatment plant.

**Recycling**. The recycling processes considered the conversion and recovery of recyclable materials, such as plastic, glass, paper, metals and compost. Plastic is recycled by mechanical systems and cold washing, converting plastics into pellets. The plant recycles LDPE, HDPE, PET, PP and PS. The processing equipment consists of the material inspection conveyor, shredder, granulator, wash plant, extrusion/decompounding. The dry grinding and shredding equipment have an $8000\,t$ capacity, with a washing and separating facility and five extrusion lines for compounding process waste back into a secondary raw material. The number of washing stages varies with the quality of the feed material and output specification. Recycled HDPE from domestic bottles is typically used to manufacture compost bins, curbside recycling boxes, garden furniture and pipes. For HDPE derived from post-consumer sources the rate was measured as about 15%, for PET the rate is estimated as 23%, 30% for PP and PS and 40% for LDPE. Glass is assumed to be converted in aggregates and asphalt. Glass asphalt contains up to 30% crushed glass which may be used as a base or binder course, intended only for use in the structural layers. The glass is crushed and screened to produce the desired particle range and to remove contaminants. The glass and the other components, aggregate and bitumen, are then mixed in a conventional asphalt plant. Metals recycling and paper recycling are considered to displacing primary production with a closed loop recycling. The offset has been derived for process energy burdens from Ecoinvent processes. Finally, the compost produced after composting process from OFMSW SC goes into topsoil, retail growing media and landscaping.

#### Interpretation

The results from the LCI and LCIA are evaluated, interpreted and compared with the results obtained by other studies conducted in similar areas for analyzing future MSWM scenarios. The LCA approach allows a sensitivity check for understanding the reliability of the selected impacts and indicators [37]. Therefore, a sensitivity analysis was also performed to check if the electricity mix and the landfill gas collection efficiency influenced the results obtained. The electricity mix change in terms of carbon emissions: low, medium and high rates (Table 4.7). The landfill gas efficiency is set to 20%, 45%, and 70%, with 20% and 70% considered as the minimum and maximum landfill gas collection efficiency for a sanitary landfill.

| Baseline Fuel Mix [%] | Low Carbon | Medium Carbon | High carbon |
|---|---|---|---|
| Coal | 0 | 15 | 94 |
| Oil | 0 | 0.5 | 1.5 |
| Gas | 0 | 7.5 | 1.5 |
| Gas (Combined Cycle Gas Turbine) | 5 | 20 | 0 |
| Nuclear | 40 | 40 | 0 |
| Waste | 1 | 0 | 0 |
| Renewables thermal | 0 | 0.2 | 0 |
| Solar photovoltaic | 1 | 0 | 0 |
| Wind | 3 | 4.8 | 0 |
| Hydropower | 50 | 12 | 3 |

**Table 4.7:** Baseline fuel mix used for the sensitivity analysis (in terms of carbon emissions). Values expressed in percentage. (WRATE database).

### 4.2.3 Results

#### Stage III: Environmental impacts assessment of the scenarios

The analysis of the scenarios allows obtaining the amounts of MSW and OFMSW disposed of to the sanitary landfill, as well as the net amount of MSW recycled. Table 4.8 reports the results obtained per scenario. The best option in terms of amounts of MSW and OFMSW landfilled is S7. Incineration of waste and AD of the OFMSW increase the amount of waste recovered for material and energy valorization. However, the best RR is obtained by S4, due to the implementation of DtD SC of OFMSW, with high SC rate, and the implementation of SSC. In terms of amounts of inorganic waste recycling, the best option is obtained with the implementation of SSC for plastic, paper and cardboard, metals and glass, in parallel with OFMSW (S2).

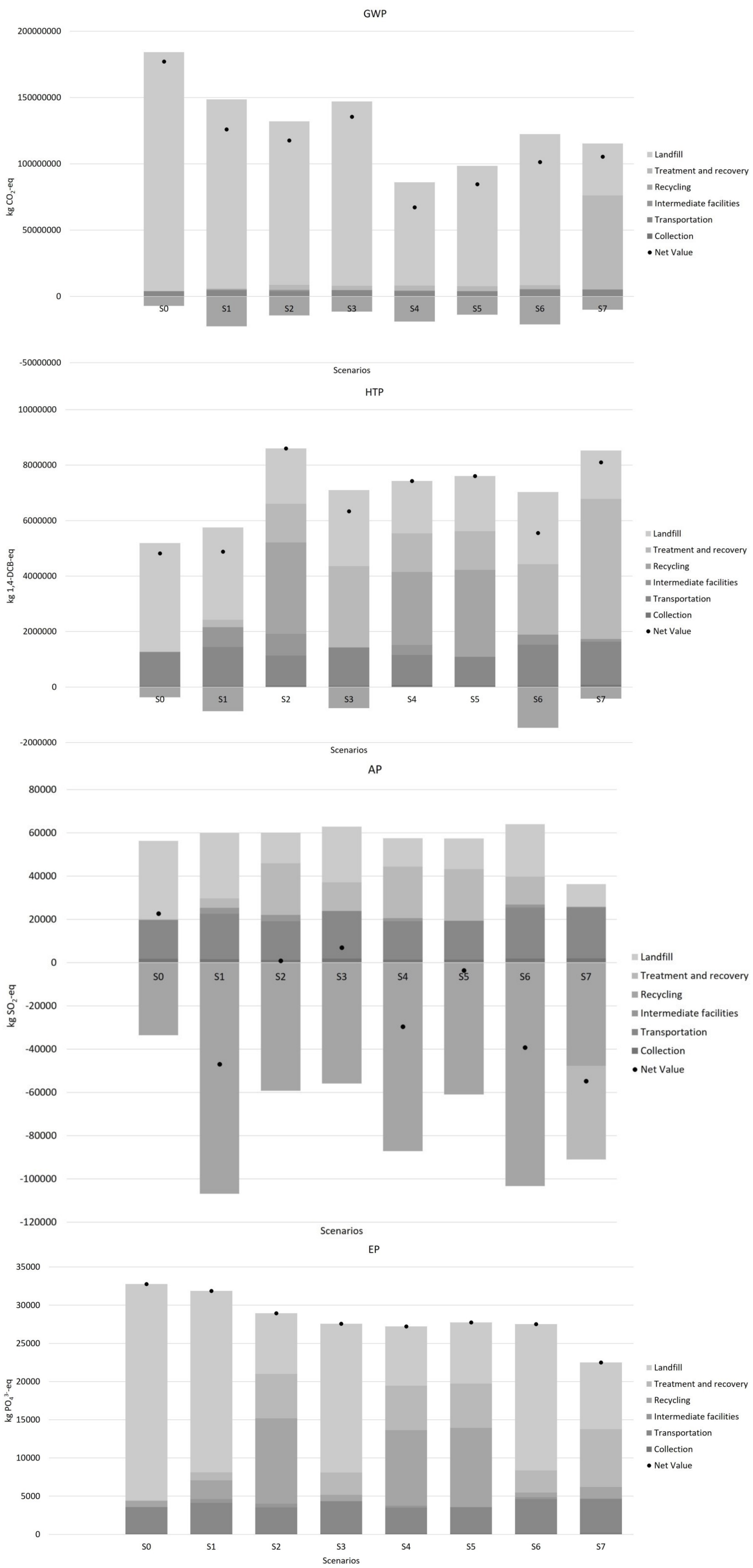


**Figure 4.16:** Environmental impacts assessment for each MSWM scenario.

In any case, the best overall RR is always obtained with the inclusion of the SC of the OFMSW, obtaining S4>S5>S2>S1> S7>S6>S3>S0. Comparing the scenarios in terms of environmental impacts, higher RR means lower GWP. Table 5 sums up the total environmental impacts obtained by the LCA for each scenario. It is highlighted that S6 has the less contribution to the GWP, while the maximum contribution is obtained by S0. The ranking obtained is S4<S5<S6<S7 <S2<S1<S3<S0. Therefore, the best option is to implement DtD SC of OFMSW and SSC of recyclable materials. Different results are obtained analyzing the AP and EP. The best option is always S7, therefore waste recovery for energy valorization. Regarding the AP, the main ranking is S7<S1<S6<S4 <S5<S2<S3<S0, while the EP provided S7<S4<S6<S3 <S5<S2<S1<S0. The worst scenario is always S0.

| Indicators | S0 | S1 | S2 | S3 | S4 | S5 | S6 | S7 |
|---|---|---|---|---|---|---|---|---|
| Waste landfilled [t] | 215,360 | 173,145 | 116,167 | 158,040 | 104,200 | 116,370 | 142,028 | 75,909 |
| Biodegradable waste landfilled [t] | 160,814 | 131,398 | 67,019 | 118,779 | 55,503 | 62,316 | 108,926 | 39,523 |
| OFMSW Composted [t] | 1460 | 18,930 | 94,827 | 1460 | 94,827 | 94,827 | 1460 | 24,802 |
| Recovery (OFMSW) [%] | 1.2 | 15.6 | 78.3 | 1.2 | 78.3 | 78.3 | 1.2 | 20.4 |
| MSW recycled [t] | 13,722 | 44,765 | 22,154 | 21,299 | 36,210 | 22,203 | 44,054 | 24,178 |
| RR (inorganic MSW) [%] | 6 | 19.5 | 9.7 | 9.3 | 15.8 | 9.7 | 19.2 | 10.5 |
| Total RR [%] | 6.6 | 27.8 | 51.0 | 9.9 | 57.2 | 51.1 | 19.9 | 21.4 |

**Table 4.8:** MSW landfilled and recycled per MSWM scenario.

It should be underlined that the changes in terms of EP are lower than 30%, while GWP and AP change of about 60% and 70%, respectively, among the scenarios. Therefore, the change in MSWM options affect more the GWP and AP than EP. Finally, HTP shows different trends, with S0 the best option and S2 the worst. The final ranking obtained is S0<S1<S6<S3 <S4<S5<S7<S2. This is due to the high amount of compost produced and used for land reclamation, with high contents of Lead, Nickel, Chromium and Arsenic that affect the soil. S7 is the second option less favorable in terms of HTP due to the incineration process. In this case, the differences among the scenarios is of about 44%. However, normalizing the results and comparing the four impacts, the one that affect the most the environment is the GWP.

| | Units | S0 | S1 | S2 | S3 | S4 | S5 | S6 | S7 |
|---|---|---|---|---|---|---|---|---|---|
| GWP | $t\,CO_2$-eq | 177,144 | 126,045 | 117,703 | 135,551 | 67,225 | 84,731 | 101,352 | 105,351 |
| | $kg\,CO_2$-eq $t^{-1}$ | 772.856 | 549.919 | 513.523 | 591.395 | 293.294 | 369.674 | 442.189 | 459.636 |
| AP | $kg\,SO_2$-eq | 22,698 | -46,951 | 872 | 6960 | -29,627 | -3621 | -39,288 | -54,807 |
| | $kg\,SO_2$-eq $t^{-1}$ | 0.099 | -0.205 | 0.004 | 0.030 | -0.129 | -0.016 | -0.171 | -0.239 |
| EP | $kg\,PO_4$-eq | 32,774 | 31,874 | 28,957 | 27,586 | 27,236 | 27,745 | 27,535 | 22,513 |
| | $kg\,PO_4$-eq $t^{-1}$ | 0.143 | 0.139 | 0.126 | 0.120 | 0.119 | 0.121 | 0.120 | 0.098 |
| HTP | t 1,4-DCB-eq | 4821 | 4881 | 8604 | 6337 | 7429 | 7604 | 5557 | 8104 |
| | kg 1,4-DCB -eq $t^{-1}$ | 21.035 | 21.297 | 37.539 | 27.650 | 32.416 | 33.177 | 24.246 | 35.359 |

**Table 4.9:** Total impact per MSWM scenario.

Comparably, the energy recovery from waste contributes to the avoidance of AP. It is obtained thanks to the reduction in fossil fuels combustion. On the other hand, the main contribution of the HTP is the incineration and the recovery of OFMSW for land reclamation, in terms of air and soil contamination, respectively. However, as mentioned before, this impact is of less magnitude than the contribution to the GWP. Finally, the EP, as the GWP, is mainly affected by the sanitary landfill, due to the generation of leachate emissions and the contamination of water bodies.

For understanding the reason of the final ranking obtained for each environmental impact, the contributions of each option and MSWM phase should be evaluated. In Figure 4.16 the main contribution of the MSWM activities to the environmental impacts are shown. In terms of GWP, the recycling of materials, in terms of substitution of virgin materials, allows obtaining a negative value (impacts avoided). The higher contribution to GHG emissions is due to the sanitary landfill, for the generation of methane and carbon dioxide. If compared with final disposal, the contribution of treatment, intermediate facilities, collection and transportation are negligible. Recycling allows reducing also the emissions affecting the AP.

### Stage IV: Interpretation and sensitivity analysis

The sensitivity analysis was implemented for understanding how the landfill gas collection rate and the different electricity mix affect the results and the ranking obtained. The results about the landfill gas collection efficiency are reported in Figure 4.17. First, HTP and EP are not influenced by the landfill gas collection rate. It affects the GWP and the AP, due to the reduction of GHG emissions and the increase of $kg\,SO2-eq$ due to landfill gas flaring. The final ranking of GWP with 70% of collection rate is S4<S5<S6<S1 <S2<S3<S7<S0.

Therefore, the landfill gas collection affects the final ranking of the most affordable scenarios in terms of GWP and it should be considered for improving the environmental impacts of the MSWM system and for comparing other options. It is an issue also reported by other authors, underlining that landfill gas recovery should be properly assessed and transparently reported especially in developing countries, because of the high generation of OFMSW [38]. At the same time, the AP final ranking changes, but S7 remains the most favorable option, while S0 the worst.

The different energy mix influences all the environmental impacts assessed. Increasing the carbon emissions due to electricity generation, the GWP increases for all the scenario except for S7, due to the energy avoided thanks to incineration and WTE (Figure 4.18). It affects the final ranking of the scenarios: the best option is always the recovery of organic and inorganic waste, while energy recovery is suggested if high the electricity mix is of high carbon emissions (intensive use of fossil fuels). At the same time, EP increases for all the scenario with the increasing of the carbon emissions, except for S7. However, in this case, the final ranking remains equal for all the electricity mix options. Considerably changes are obtained in function of the AP. The worst scenario with high carbon emissions is S3 and the best S7, while with low carbon emission the worst scenario is S0 and the best S1. It is because S1 has a higher RR and small treatment plants for other fractions, reducing the use of electricity. Therefore, incineration is recommended when electricity mix is mainly generated with combustion of fossil fuel, while recycling is the most option when renewable energies are used. Finally, HTP is also affected by the change in electricity mix, increasing the impacts in coherence with the increase in fossil fuel consumption. Again, the final ranking change, in particular for S6, where the electricity used at the MBT considerably affect the HTP. The final part of the interpretation, where the results of other studies are compared, is introduced within the discussion section.

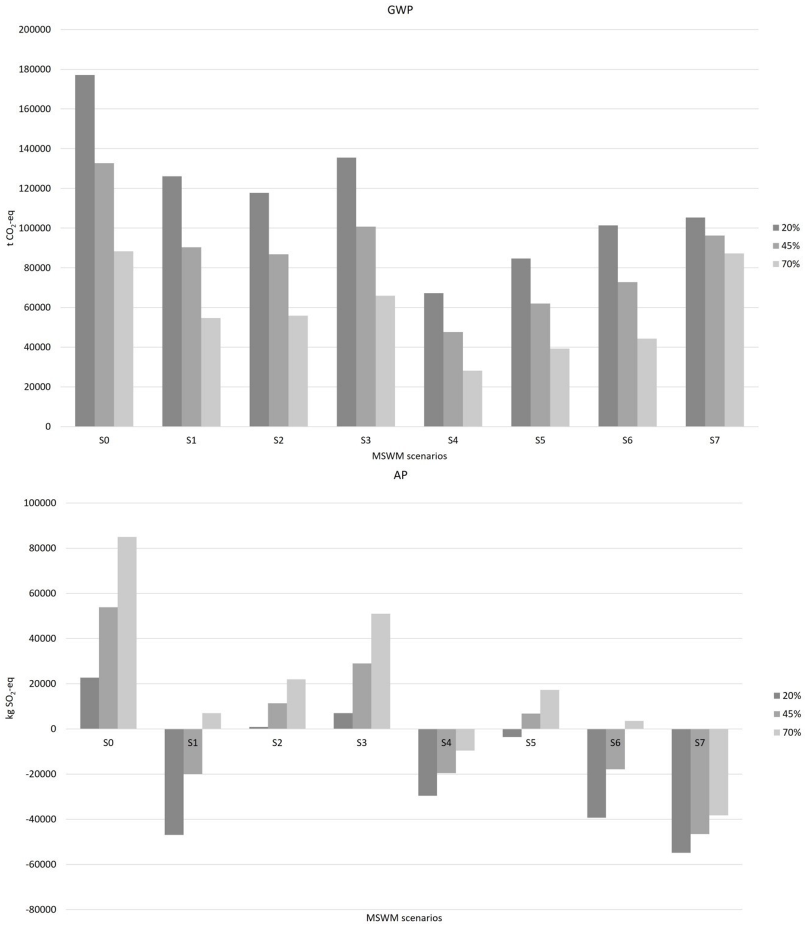


**Figure 4.17:** GWP and AP for each scenario in function of the LFGCE.

### 4.2.4 Strengths and Limitations of the study

The study conducted in La Paz has limitations in terms of data quality and availability. The use of academic licensing, limited in terms of database and inventory, does not allow avoiding bias in LCIA. In general terms, the environmental impacts obtained are only indications about the ecoefficiency potential of the MSWM scenarios introduced. However, the ranking obtained can be the first step for introducing studies for improving environmental performances of MSW collection and treatment systems. Hence, the values obtained can be used for understanding main pros and cons of the systems, evaluating where the political and technical improvements should be focused.

The main potentiality of the research consists in introducing LCA in areas where this approach is not known without economic requirements. It can be achieved only with the cooperation between the University, which can obtain academic licensing and providing technical information about how and why the LCA should be applied, and the local Government, explaining to local stakeholders the pros and cons of an LCA.

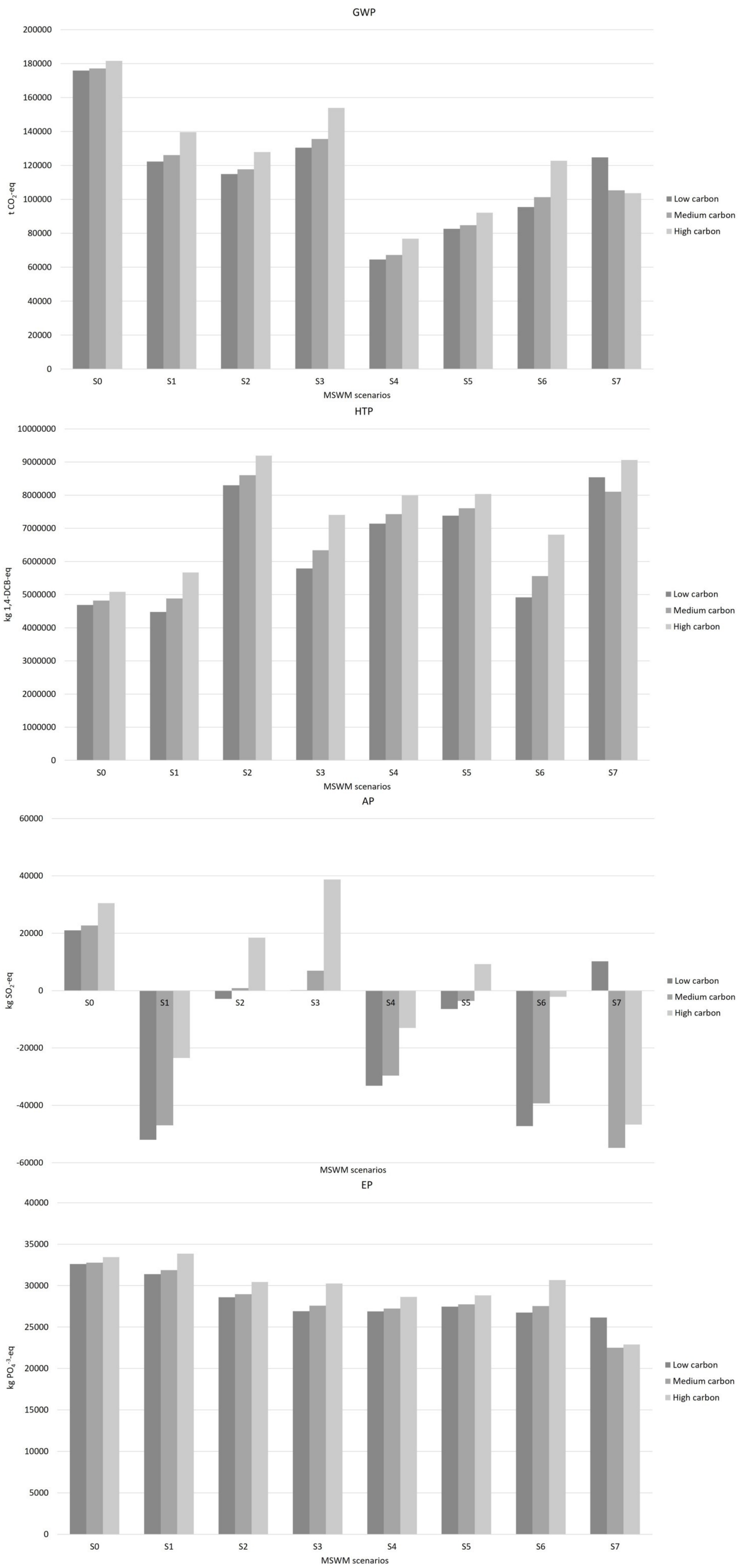


**Figure 4.18:** Environmental impacts assessment for each scenario in function of the electricity mix

In addition, the MFA analysis and the comparison among the scenarios allow showing the importance of the presence of the informal sector in MSW recycling, which contributes in reducing environmental impacts and increasing the RR of the MSWM system of the city, and the sensitivity of the MSWM system in terms of treatment and collection option.

The scenarios presented are possible long and short terms MSWM systems that La Paz can adopt for improving environmental sustainability. The analysis underlined that the main advantages are obtained if the organic fractions are separated and treated for energy or material recovery, reducing GWP. At the same time, WtE are also strategies that should be adopted in order to reduce the use of fossil fuels, avoiding GHG emissions.

However, the main issue is to implement such strategies, in terms of financial risk, technical knowledge, local expertise in operation and management, social inclusion and acceptability and the presence of the informal sector. These issues are the main barriers for improving in short terms the MSWM system of La Paz, although many efforts were implemented in the last years. Other analysis should be introduced with specific tools and approaches, such as life cycle costing, social surveys, geographic information systems, in parallel with the assessment of other waste fractions. These analysis, the national and international cooperation with stakeholders, and the support of international funders can boost the implementation of these scenarios, in contexts where the growing delays are around decades compared to high-income countries.

### 4.2.5 Comparison with other case studies

Other LCA studies in developing countries were implemented for estimating environmental impacts due to MSWM. A study conducted in the island of Mauritius with Simapro 8.0.4.30 shows that landfilling with energy recovery is the most undesirable scenario, generating the worst environmental impacts compared to other MSWM systems. From an environmental point of view, the study recommended to consider incineration of waste with energy recovery [39]. In Panchkula, India, a research conducted with SimaPro 8.3, determined the impact of MSWM scenarios. Among the proposed alternative scenarios, the combination of recycling, composting, and sanitary landfill showed the lower environmental impacts, with significant environmental savings achieved through energy recovery [40]. In Hangzhou, China, using Gabi 8.0 software, a study found that incineration has better environmental performance than landfill, while selective collection of recyclable waste can reduce the negative effects to the environment, recommending AD as a primary option for food waste treatment [41]. In Sakarya, Turkey, the analysis with SimaPro 8.0.2 of the local MSWM system (landfilling without any biogas recovery), reported that landfilling and incineration are the worst waste final disposal alternatives, while composting and material recovery showed better environmental performances [42]. In Mumbai, India, a research conducted with GaBi v6.0, shows that the significant environmental savings are achieved through the energy recovery. In particular, the combination of composting, AD and landfill were found to be the most preferable options [43].

Therefore, all studies conducted with LCA are in accordance in terms of MSWM strategies for reducing environmental impacts. The implementation of AD, incineration with energy recovery, composting and material recycling, in parallel with controlled sanitary landfills, are always the most preferable option in term of environmental impacts. Therefore, the main issue is not about the choice of the best option, but its implementation in developing areas, where know how and financial sustainability are not enough for guarantying and efficient policy implementation. For this reason, it is important to spread knowledge and the application of management tools useful for planning solutions and understanding local issues.

The study presented in this paper obtained similar results of previous researches conducted in other developing countries with full licensing software. The comparison of the data obtained provide good indications about the reliability of the results of this study, although without specific databases and with academic licensing. This consideration has been also introduced by others reviews papers, where the GWP of the MSWM scenarios has been found to range from -740 to about 1900 $kg\,CO_2 - eq\,t^{-1}$, while AP ranges from -4.60 to about $2.37\,kg\,SO_2 - eq\,t^{-1}$ [44], from the best to the worst MSWM option. Moreover, LCA results have been found to be independent from the choice of software if the models are based on the same assumptions [31]. These information are useful for understanding the values obtained and they should be presented in parallel with the data obtained by the LCA implemented locally, justifying to the policy-makers which consequences has the lack of data and the use of an academic license, as well as the choices in life cycle modelling.

### 4.2.6 Lessons learned and future improvements

The results obtained by the LCA introduced in this paper are not important as quantitative values, but for providing indications about the best and worst option, focusing on the main actions that can have a positive or negative environmental impact. For example, landfill gas flaring allows reducing the GWP, increasing the AP. At the same time, open burning of waste increases the HTP, as well as GWP and AP, while recycling and energy recovery allow reducing mostly all environmental impacts, as also reported by the scientific literature [45, 46]. Such information, in parallel with a complete MFA, allows policy-makers to understand which are the main actions that should be implemented for justifying the improvement of the MSWM system in an environmental point of view.

The sensitivity analysis added other useful indications about the issues that should be addressed for ranking the best and worst MSWM scenario in terms of environmental impacts. The energy mix used in the country and the percentage of landfill gas recovery affect the LCIA, changing the ranking of the best and worst scenario. These issues can be explained to local stakeholders and can be used as environmental indicators for understanding the main pros and cons of the actions implemented or planned.

These results were shared with stakeholders and engineers of La Paz for improving their knowledge about MSW planning. The application of an LCA free of charge allows its application in low-middle income countries as long-term teaching tool for spreading knowledge and awareness about environmental issues. The experience conducted for applying the LCA in La Paz allows writing, submitting and starting an international cooperation project financed by the Italian Agency for Development Cooperation (AICS) in collaboration with the local Government, the Academy and an Italian NGO, using the LCA (with full licensing and complete databases) as technical approach for assessing the pre and post design environmental impacts as indicators of the improvements obtained thanks to the MSWM project (see chapter 5.1). Therefore, the application of LCA with academic licensing was the first step for starting international cooperation projects, demonstrating that the cooperation with local and international stakeholders is compulsory for finding international funds.

Other experiences agreed that the cooperation of Governments and Universities, among other actors, through training courses and seminars might help in improving the LCA applicability in the field of MSWM, providing proper information along with the implication of more environment-friendly policies and actions [34]. In order to advance toward circular economy, new policy are required for technological innovation and MSWM improvements [47]. At the same time, reduction in environmental impacts are required internationally and the decrease in GHG emissions in developing countries requires technological and financial assistance from developed economies [48]. Life Cycle Thinking and LCA can be useful tools for supporting sustainable development, if their results are interpreted with their respective limitations [49]. In particular, impacts on human health should not be limited by the results of LCA, since they can be higher on the surrounding of the MSW treatment plants, taking to misleading decisions and underestimating real impacts [50]. Therefore, the application of LCA in MSWM, in parallel with the national and international cooperation among various actors, should be encouraged and spread in developing areas, where the technical knowledge starts most of the time from zero, in order to increase sustainability at global level.

### 4.2.7 Remarks and considerations

Improvements of MSWM systems in developing countries are challenging. La Paz is a developing context where technical and financial support is required for boosting sustainability in short terms, since global warming and climate change require urgent solutions. The LCA of MSWM system scenarios implemented in La Paz is another contribution to the scientific literature for understanding the pros and cons of an LCA implemented in low-income regions with the lack of financial sustainability for understanding environmental opportunities of waste valorisation.

The paper explores the main advantages of the academic licensing (free of charge) of an LCA software for analysing the MSWM options in terms of environmental impacts. Results demonstrated that the ranking obtained are in coherence with the ones provided by other studies, as well as the final values obtained. The first assessment of MSWM scenarios, although with the lack of data and reliable inventory, can be potential for improving awareness and methodological knowledge in areas with low technical and economic availability. The scientific and political cooperation, together with the knowledge in management tools like the LCA, can be used for finding international funds that can be used for improving the MSWM system implemented at municipal level.

The next studies will be focused on the implementation of an LCA with full licensing and complete inventories, comparing the results obtained with more consistent data. This study, as well as future implementation, can be of interest for stakeholders of low-middle income countries for the implementation of the approach and for starting international cooperation projects for improving the MSWM systems towards circular economy and sustainable development.

## 4.3 How to assess formal and informal SC systems future scenarios: an integrated assessment with QGIS

This research refers to the article *"Assessment of municipal solid waste selective collection scenarios with geographic information systems in Bolivia"* (Ferronato N., Preziosi G., Gorritty Portillo M.G., Guisbert Lizarazu E.G. and Torretta V.) submitted to the *Waste Management* Journal and currently under review (Major revisions).

### 4.3.1 Introduction

Informal recycling is a common practice in low-middle income regions [51]. Waste pickers collect recyclable waste, such as plastic, paper and cardboard, implementing a first (informal) circular economy scheme for reducing environmental impacts and spreading local economies [52, 53, 54]. However, this practice is mostly unassessed and unconsidered in the formal MSWM and planning [55], increasing the bias in estimating the waste inflow into final disposal sites, treatment plants, and collection trucks. Therefore, its activity should be measured for planning future improvements in MSW collection and treatment scenarios.

Planning MSWM systems can be supported by the use of strategies and tools more or less holistic, such as indicators [56], life cycle assessment [57], MCDA [58], and risk assessment [59]. For assessing economic and environmental impacts in MSW collection, the common tools used are GIS [60, 61, 62, 63]. Mainly, the assessments consider timing routes, traveled distances, traffic congestion and the number of vehicles [64], analyzing the direct effect of environmental impacts [65]. However, the researches that implemented these tools often do not consider the informal recycling activity, focusing on the formal MSWM system implemented by local municipalities.

The GIS was shown to be an efficient decision support tool to investigate the impacts of future MSW system scenarios in terms of environmental impacts and costs [66]. Various studies suggest implementing GIS modeling for assessing the yield of the MSW collection systems in developing countries. In India, optimal MSW collection and transportation scheme show that collection planning with GIS is able to reduce more than 30% of the total waste collection path length, saving environmental impacts and expenses [67]. In Vietnam, the application of GIS shown that both total traveling distances and operational hours of vehicles can be reduced [68]. In Malaysia, five routes were assessed for the pilot study and the current routes were optimized reducing up to 22% length [69]. In Algeria, the optimization of the routes by GIS has enabled a reduction of traveled distances, collection time, fuel consumption and polluting emissions, taking into account the state of the road, the vehicles speed, the vehicles load and collection frequencies [70]. These studies conducted in developing areas obtained similar results, suggesting the implementation of GIS for reducing costs and environmental impacts. However, there is not any mention of the inclusion of waste pickers in terms of amounts of recyclable waste collected, the number of containers reduced and the economic saves. Therefore, the main question addressed in this research is: what about the inclusion of informal recycling is GIS analysis?

In this section, the application of GIS was introduced for assessing possible MSW management systems scenario in La Paz, Bolivian developing city where the implementation of SC activities is in its first stage. The research would assess the short and long term scenario that considered the SC of recyclable and organic waste, taking into account the recycling chain carried out by the informal sector. The MSW to landfill, the recycling rate, and the economic expenses were measured, as well as the path of the transportation routes. In particular, four scenarios were considered: the collection of mixed waste and implementation of MBT before landfilling, the implementation of SC by SSC, the introduction of curbside collection of organic waste, and the overall assessment with the inclusion of the informal sector. The aim of the work is to analyze the main economic challenges and waste recovery opportunities of the implementation of SC scenarios considering the contribution of the informal sector currently active in the city, trying to answer to the question previously introduced.

The approach presented in this paper represents a novelty for the scientific literature since in developing context the optimization of transportation routes is assessed by GIS without considering the activity of the informal sector. The research is an attempt for estimating economic and operational advantages of the inclusion of waste pickers in the MSW management planning. The method, as well as the results, can be of interest for policymakers and scholars involved in the implementation of the circular economy in low-middle income countries, where the lack of financial support, political will, public awareness and the presence of informal recycling are barriers that should be overcome for reducing environmental impacts and boosting sustainable development.

### 4.3.2 Overview of the methods

The use of GIS was considered the most appropriate method for calculating the area covered by the formal and informal collection, the cost-saving due to the presence of the waste pickers and the reduction in investment costs due to the informal MSW recycling streams. The research took place in La Paz (Bolivia): A first analysis of the current MSWM system implemented in the city was carried out through interviews to local stakeholders, participation in seminars and workshops, site visits and review of local documentation. These researches were implemented from 2016 in cooperation with local stakeholders. Afterward, a post-processing phase was implemented with the GIS software QGIS3.8, introducing the road infrastructures, the morphology of the city, the amount of MSW generated per inhabitant, and the location of the containers. The outputs of the analysis are the quantities of waste yearly gathered and the routes for its collection converted in terms of km traveled during a year.

The baseline scenario has been built in the GIS environment in a pilot district of La Paz, while four scenarios were introduced in order to evaluate the theoretical MSW inflow into the final disposal site, the recycling rate obtainable, the km traveled and the costs of the system. Therefore, the study is divided in four main parts: (1) database and base map implementation, (2) construction of the scenarios, (3) evaluation of the four scenarios for the management of MSW separate collection in the pilot area, and (4) comparison of the proposed scenarios, considering the main pros and cons of the presence of the informal recycling sector. The functional unit for assessing the MSWM scenarios is the annul MSW generated in the study area.

#### Area of the scenarios' assessment

The analysis was conducted in a small part of the city, in order to simplify the whole GIS analysis. The criteria used to select the area within the municipality are the economic level, the production of MSW, the type of SC implemented, the presence of the informal sector and the number of inhabitants. These data were gathered by previous analysis. In particular, the area considered is inhabited by medium to high income households, therefore with a relevant production of MSW. The formal SC by SSC has already been implemented in some neighborhoods of the same district. Moreover, the district considered contains about 58,409 inhabitants, about 13% of the city, with a daily production of MSW about $44t\,d^{-1}$, about 7% of the waste generated at municipal level. These data are introduced according to the information available in a study conducted in 2012 [71], and in function of the projections of the MSW generation rates and population growth rate from 2008 to 2018. The amount of waste generated, function of the economic level and population density, and the boundaries of the district considered for the analysis are reported in Figure 4.19.

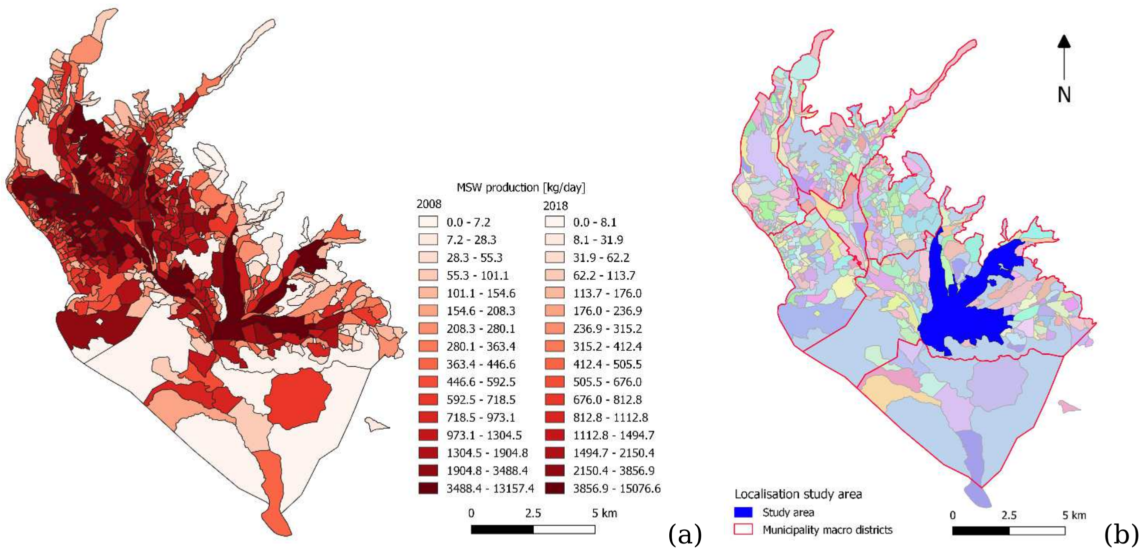


**Figure 4.19:** (a) MSW generation per neighborhoods in La Paz and (b) study area for implementing the analysis.

**Location of the informal SC**

The number of waste pickers and recycling shops operating in La Paz was made considering the study of the NGO Swisscontact, conducted in 2008 [73]. The study contains the working areas of waste pickers and recycling shops in La Paz. Totally, 176 points of operation of the waste pickers and 89 recycling shops were counted, 15 of them contained in the area of scenarios assessment. The study identified that about 1300 waste pickers are working in the city of La Paz. About 7 to 10 waste pickers work in each point identified, considering the individuals forming part families or groups of workers. Every day, the informal sector has the capacity to intercept about $30-40t\,d^{-1}$ of recyclable waste, with the capacity of $20-30kg\,d^{-1}$ per waste picker. It means that about 6-7% of the total MSW generated in the city is recovered by the informal recycling sector, mainly gathered from waste bins, containers, or waste bags left along the roads. On average, it has been estimated that a waste picker collects about 45.6% of paper, 28% of plastic, 20.7% of cardboard, 2.2% of cans and 3.5% of glass. The area of operation is difficult to estimate due to the itinerant characteristic of these workers. However, it could be estimated that waste pickers are organized in specific areas of the city, covering a range of about 500m each (about $0.8km^2$).

These information are useful for evaluating the amount of recyclable waste theoretically gathered informally by the waste pickers in the city. It has been considered for planning and quantifying the amount of waste that is not collected by the system, therefore that does not inflow into the final disposal site or treatment plants. The location of the waste pickers and recycling shops that operate in the city was reported in the QGIS environment and depicted in Figure 4.20.

The hypothesis is that the waste pickers can be recognized both by the population and the local government, with a list of operators working in the area, with a license, and with a uniform for working in a specific area. Therefore, its activity can be accepted by the stakeholders and enter into the MSWM planning phase. The main pros for the waste pickers are cleaner and safer SC, a certain amount of waste collected per week with limitation of the itinerant activity and a recognized labor from the citizens and authorities, as mentioned in section 3.1 [52].

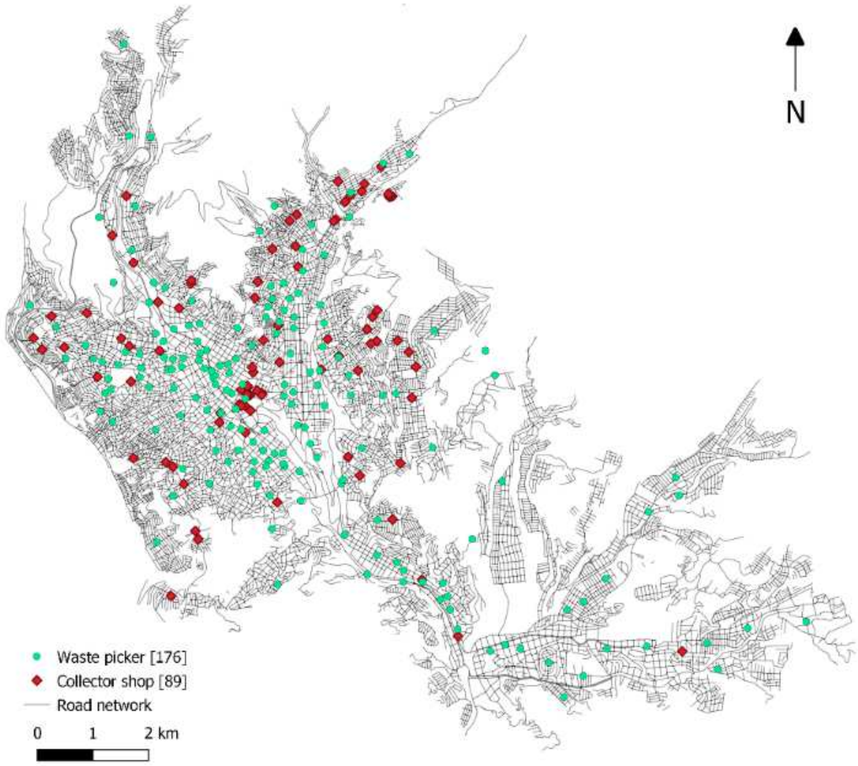


**Figure 4.20:** Location of the waste pickers and recycling shops of La Paz, according to [73].

**MSWM system scenarios and hypothesis**

In this section, the scenarios assessed are briefly described along with the main hypothesis made for the analysis with QGIS. Four scenarios have been developed in this research considering the main political will and infrastructure available in La Paz and in Bolivia, as assessed in a previous study [74]. Therefore, incineration and anaerobic digestion were not taken into account for developing SC scenarios. The analysis considered the MSW life cycle, starting from the generation (collection bins), the collection and transportation (containers and transportation trucks), treatment and final disposal. Public awareness, citizens’ acceptance, regulations and laws, the market of recyclable materials, environmental impacts and the location of the treatment plants were not involved in the analysis.

**Scenario 0** (S0). It is the baseline scenario of MSW collection and treatment currently implemented in La Paz. The MSW collection system is implemented by mixed containers, collected by compactor trucks and disposed of in the municipal sanitary landfill with no pre-treatment. The SC system implemented at pilot scale in a few neighborhoods of the city was not inserted in the scenario, neither the activity of the informal sector. The hypothesis is that all MSW produced in the study area is collected by the formal MSWM system.

**Scenario 0.1** (S0.1). It takes into account the short-term implementation of a double-streams MBT plant. S0.1 has the same characteristics of S0. The main difference consists in the implementation of a pre-treatment system before landfilling for the recovery of metal scraps and recyclable plastic waste, with a post-treatment process for the stabilization of the OFMSW. Its implementation can be considered for increasing the useful life of the sanitary landfill since the MSW collection system does not require any improvements, while the main investment costs are related to the treatment plant. Therefore, it is a short-term solution for reducing environmental impacts and for starting the implementation of MSW treatment systems in an area with low recycling rates [76, 75].

**Scenario 1** (S1). It foresees the implementation of MSW SC system by SSC. Three separate containers are introduced for separate collection of paper and cardboard, plastic, and mixed waste. In the study, the three containers are located in the same collection point. The recyclable waste collected separately is delivered to MRF, while the mixed waste is disposed of to the final disposal site. The investment cots for the implementation of the SSC, the specific collection routes and the construction of the MRF required for selecting the waste are considered in this scenario.

**Scenario 2** (S2): The SC by SSC of S1 is implemented in parallel with the curbside collection of OFMSW. Therefore, the amount of mixed waste is reduced, while the amounts of OFMSW are treated in a composting plant in order to produce compost, avoiding the final disposal of this waste fraction. Therefore, the expenses for the curbside collection, the investment for the specific waste bags and the investment costs for the implementation of the composting facilities are evaluated.

**Scenario 3** (S3): The last scenarios included the implementation of S2 taking into account the amount of recyclable waste collected by the informal sector. The collection routes, the number of containers, the amount of waste collected and the investments for the construction of new MRF are finally assessed for highlighting the expenses reduced thanks to the involvement of the waste pickers.

For allowing an easy assessment of the MSWM costs, some hypotheses were made: (1) the number of containers and emptying routes were calculated with the maximum daily MSW weight amounts theoretically produced by the population; (2) The income deriving from the sale of recyclable materials are calculated with the maximum target of SC achievable by the systems; (3) the proposed scenarios are considered in their complete applications, therefore with no timescale or dynamic assessment; (4) the limits of the road network, such as the one-way streets, the width, or the slope have not been considered for the collection routes.

### 4.3.3 Methods - Dimensioning and location of MSW containers

#### Density of the MSW fractions

MSW density is required in order to dimension the containers required for its collection. Data about the densities of MSW collected by the SC system are not available at city level, due to the lack of monitoring, data analysis, and field studies. A literature review was conducted in order to obtain a general density of the waste collected per MSW fraction [78, 79]. The arithmetic mean of the values collected in literature was calculated, as well as the standard deviation. For obtaining the density of the mixed MSW, the factions available in this stream were considered, such as the OFMSW, metals, glass, textiles and others non-recyclables. For the scenarios that foresee the implementation of the OFMSW curbside collection, the density of the mixed waste was calculated with a smaller amount of organic waste, weighting the percentages detectable within the mixed waste.

Therefore, the densities used for this study are: for paper and cardboard $283.4 kg\, m^{-3}$ $\pm 110$, for plastic waste $58.6 kg\, m^{-3}$ $\pm 27$, for mixed waste $558.8 kg\, m^{-3} \pm 144$, for OFMSW $687.6 kg\, m^{-3}$ $\pm 161$, while for mixed waste with low amounts of OFMSW is $312.5 kg\, m^{-3}$ $\pm 114$. For paper and cardboard, the high standard deviation value depends on the percentage of cardboard available within the MSW and the moisture content of the material. The OFMSW density depends on the composition of the waste that can undergo considerable variations [80].

#### Dimension and collection time of the mixed MSW containers

Knowing the amount of mixed MSW generated in the area (about $44 t\, d^{-1}$) and its density ($558.8 kg\, m^{-3}$), it is possible to obtain the volume required for its collection. The total volume accumulated in one day was therefore calculated (about $211 m^3$), and the collection time imposed. Totally, three emptying per week were hypothesized in accordance with the standard for guaranteeing public hygiene [81]. The total volumes produced have been increased for a percentage of compensation of 15% for mixed waste, useful to consider calculation errors and periodic fluctuations in the production of MSW per capita.

In the design, $2.5 m^3$ containers were used in accordance with the containers currently located at municipal level. To this volumetric capacity, 10% of capacity has been reduced as safety filling volume, in order to cope with any theoretical daily overproduction. By reducing this percentage, the actual volume of the container, considered in the calculation phase, was equal to $2.3 m^3$. The minimum number of containers for collecting the total amount of mixed waste with three days of retention time (from Friday to Monday) is equal to 276 units. After arranging the calculated minimum number of containers in terms of volume, the user-container distance was also verified. Therefore, the minimum number of mixed containers should guarantee both the filling volume and the distances from the generators.

#### Location of the MSW containers

The location of the road containers was calculated assessing the maximum distance suited for the position of MSW container. The distances considered are linear distances along the road network. The maximum value of 300m was used, reflecting the maximum indicative value for road containers [82], specified within a range between 80m and 300m, taking into account that the lower the distance is, the higher the selection rate value will be [83]. The model returned a total of 282 points. The main information obtained is that the 276 units previously obtained by the calculation of the minimum volumes required are contained in these distances. Therefore, the number of containers maintained was of 282, with a minimum linear distance of 290m and a maximum of 320m, function of the population density in the specific neighborhood, verifying that the minimum volumes required were covered. These distances allow balancing the economic investment for the implementation of the SSC, the cover of the area for guaranteeing the collection of the MSW, and the reliability of its implementation in the study area for local citizens.

#### Curbside collection

The OFMSW collection system is implemented door to door in order to improve the quality of the organic fraction collected. The main objective is to produce high-quality compost, as specified by other studies [84, 85]. The study considered the delivery of a family litterbin and paper bags to every household. To all commercial or institutional users, 120L or 240L wheeled cans were accounted to be provided. The users are responsible for washing the bins or the wheeled bin and the same bins or wheeled bins should be brought by users to a public road area in front of the street, allowing the curbside collection. These details of the collection design are required in order to estimate the management costs. For the design and calculation of road containers, the same analysis of the street containers was implemented, taking into account the daily volumes produced, dividing by the volumetric capacity of the containers (reduced by safety factors) and finally multiplied by the days of emptying.

### 4.3.4 Methods - Analysis of MSW collection routes

#### MSW collection design

The study involved the analyses of the kilometers traveled by the compactor trucks for emptying the street containers and disposing of the MSW to the final disposal sites. The number of routes required for emptying the containers was calculated in function of the density of the compacted MSW, equal to $650\,kgm^{-3}$. Each route is characterized by a total volume between $5m^3$ and $20m^3$, as minimum volume transported to justify the operation cost and the maximum load capacity of the vehicle. Dividing the total amount of mixed MSW produced with the density of the compacted waste, it is possible to obtain the minimum number of routes necessary for emptying the containers. Through the use of the QGIS software, the collection route was created and the kilometers required for its entire drive were calculated. A distance of 20km has been added to the kilometers of the single route, as round trip from the study area to the final disposal or treatment facility, for every single route.

#### MSW collection time

The design of the number of weekly emptying was calculated taking into account the minimum standards of hygiene and the amount of waste generated per area [82]. Mixed and organic waste collection time range from three times per week to seven times per week; cardboard and paper range from one to three times per week, while plastic should be collected from two to three times per week. Considering the local environmental conditions (average yearly temperature less than $20^oC$), the collection of mixed and OFMSW was fixed to three times per week and the collection of plastic waste two times per week. For paper and cardboard, it is possible to further increase the collection time because it does not involve significant health problems. It was therefore fixed the collection time for one time every two weeks, due to the low production rate. The volumes involved are different during the weeks: this aspect was taken into account as it affects the number of routes required for emptying containers in the weekly planning. On Monday, more collection routes will be needed compared to Wednesday and Friday since there is an additional accumulation day during the weekend.

Given the number of collection routes required per day, the length of every single route was calculated. The calculation was performed considering the number of containers that can be emptied by a single-vehicle, taking into account the maximum filling of the compactor trucks. Then, once the route had been created on QGIS, the minimum ($5m^3$) and maximum ($20m^3$) of MSW volume per collection route was verified. The distances obtained for each route has been multiplied by the number of routes needed to empty the containers, for obtaining the weekly km traveled to recover the total amount of MSW.

**Curbside collection of the OFMSW**

In the second and third scenario, the amount of mixed MSW has been reduced due to the curbside collection of the OFMSW. Therefore, health issues due to the putrescible faction in mixed MSW are reduced, in parallel with the low mixed MSW production in terms of volume (65.7% of mixed waste is now converted in a separate stream). The collection design changed, reducing the emptying time of the mixed container to one time per week. At the same time, the curbside collection of OFMSW was assessed in terms of volume produced in each area.

### 4.3.5 Methods - Estimation of the MSW disposed and formally recycled

The volume of recyclable waste collected by the SC system are theoretical since not all the quantity of MSW available in the SSC is recyclable. The total volume collected contains a percentage of rejects and unrecyclable waste that should be removed for assessing the real amount of waste recycled. The hypothesis made was that the SC of recyclable MSW reached 50%, while 70% was considered for OFMSW. These percentages are gathered by the SSC and curbside collection respectively, while the other amounts are disposed of with the mixed MSW. From these quantities, the efficiency of the SC system should be taken into account, as well as the recovery efficiency. For that purpose, the data provided by Rigamonti et al. were used, in order to obtain the final recycling efficiency of the waste collected [86]. In particular, 85.5% was obtained for paper and cardboard, 58.75% for plastic and 30% for organic waste. As regard the recyclable waste recovered by MBT, data provided by the scientific literature were reviewed. In particular, it has been estimated that the mechanical selection allows the recovery of 30% of plastic, 15% of glass and 60% metals of the ones available in the MSW delivered to the plant [87]. The results provide the amount of waste theoretically sold to the recycling companies and effectively recycled, while the rejects are disposed of in the sanitary landfill.

### 4.3.6 Methods - Estimation of the costs

The analysis of the costs comprehends the investments and the operation and maintenance of the SSC, mixed containers, family dustbins and paper bags, the collection activity of the compactor trucks, the investment and maintenance costs of the MRF, composting plants and sanitary landfill. The costs that are not involved in the study are the managerial expenses, the street sweeping, park maintenance and the collection of the hazardous waste, the investment costs of the compactor trucks, the monitoring system and the public information campaigns. Therefore, the expenses assessed are the main ones where the informal sector can be involved. Finally, the incomes due to the recyclable waste and compost sold to local private companies were took into account. These items are calculated taking into consideration different price lists obtained by the scientific literature, by technical reports or by local data available. The involvement of the informal sector was assessed in terms of municipal costs avoided thanks to its operation.

#### Final disposal and implementation of the MBT plant

The cost of the final disposal to the sanitary landfill was obtained by local documentation, and it is evaluated in function of the tons of MSW finally disposed of. The cost is of about $14.5\,t^{-1}$ (12.8€ $t^{-1}$). As regard the implementation of the pre-treatment plant before landfilling, data were gathered from the study of Munnich et al., who provided the initial investment, management and operational cost of an MBT in low income and high income regions [88]. The investments costs for a low-technical MBT in low income countries range from 10-30€ $t^{-1}$, while the operational costs range from 8-12€ $t^{-1}$. Within the investment cost, the construction charges and the purchase costs of the necessary machinery are summarized, with an amortization of 10 years. For the operation costs, the expenses for the employment and the operation of the electrical-mechanical devices are included. In the cost analysis presented in this paper, the average expenses of $15\,USD\,t^{-1}$ (13.2 € $t^{-1}$) for investments and $10\,USD\,t^{-1}$ (8.8€ $t^{-1}$) for management were used, for an MBT with the capacity lower than $20,000t\,y^{-1}$.

#### Emptying costs and implementation of the containers

The collection costs were assessed taking into account the MSW collection method. In particular, the km traveled by the compactor trucks were considered both for the curbside collection of OFMSW and the collection of mixed containers without SC, while the SC with SSC were assessed in function of the number of containers emptied per day. In this way, it is possible to discriminate the costs in function of the type of waste gathered.

Due to the lack of data available locally, the costs were obtained by the review of international technical reports. Six case studies were considered in order to obtain an average value. For collecting the mixed waste, the average cost obtained is 2.42€ $km^{-1}$ $\pm 0.53$, while for the curbside collection the average cost is 2.83€ $km^{-1}$ $\pm 0.81$ [89, 90, 91]. Concerning the SC with SSC, the average costs considered per emptying are 10.23€ $\pm 2.65$ for paper, 9.91€ $\pm 4.21$ for plastic and 4.27€ $\pm 0.65$ for mixed waste [92, 93, 94]. These results were used for quantifying the expenses of the collection routes acquired with QGIS.

#### Implementation of the MRF and composting plant

The costs of the implementation of an MRF were estimated in function of the general expenses that can be found in Bolivia for the implementation of a manual selection plant with the capacity of about 10-15 tons per day, where nine workers operate for five days per week. The cost for building the plant is of about €200,000, with amortization of about 15 years (about 13,500€ $y^{-1}$). The operation and maintenance can be estimated with about €10,000 per year, similar to the energetic costs (electric) that can be of €10,000 for an engine of 50kW. Finally, the cost of the workers can be estimated of about €56,000 for a total of about €90,000 per year for a manual selection plant of about 4000-6000 tons of recyclable waste treated per year.

The cost of a composting plant is not available in Bolivia since there are not large treatment plants built in the country. Therefore, technical reports were reviewed for estimating an average cost. Three projects of composting plants with average dimensions, from 7000 to 50,000 tons of OFMSW treated per year, were considered and reviewed [95, 96, 97]. Considering an amortization of 15 years, the average cost of the plant is about €39,500 per year. The maintenance costs can be quantified as 11.9€ $t^{-1}$ of waste inflow into the plant, while the energetic expenses are estimated of about 4€ $t^{-1}$. Finally, the cost of the manpower can be estimated as 6.9€ $t^{-1}$. Therefore, the yearly cost for a composting plant with capacity of about $6000t$ can be estimated as €180,000. Again, these costs are modulated in function of the amount of waste yearly collected for each scenario.

#### Incomes due to MSW recycling and composting

To the total computation of the costs, the income due to the recyclable MSW and compost produced should be added in terms of negative value. The average price of recyclable plastic and paper are obtained from the Bolivian market. Plastic waste can be sold directly to the recycling company for about 370€ $t^{-1}$, while paper and cardboard 260€ $t^{-1}$. These costs provide only an indication of the income achievable and do not consider the quality of the material nor the type of waste provided. As regard the compost produced after OFMSW treatment, there is not a Bolivian market available for comparing the costs. Therefore, the income due to the compost production was gathered from technical reports [96, 98] . On average, the cost per ton of a compost obtained by OFMSW selective collection can be estimated to about 11€ $t^{-1}$.

### 4.3.7 Results

#### Recycling rate

The development of the proposed scenarios leads to a gradual reduction of the MSW disposed of to sanitary landfill. The total quantity data are shown in Figure 4.21. In particular, referring to S0, the implementation of an MBT allows the reduction of MSW of $1952.1t\,y^{-1}$, equal to 12.3%. This is due to the 30% reduction in the mass of OFMSW, and the recovery of plastic and recyclable metals. On the other hand, the introduction of separate paper and plastic collection allow reducing about $1901.1t\,y^{-1}$, for 11.9% of recycling rate. This percentage is lower than the net waste value avoided by S0.1 since this value does not represent the reduction of landfill mass, but the net recycling level obtained in the study area. This is better represented in Figure 4.21, which shows that the recycling level of S0.1 does not exceed 4%, even if the level of waste at landfill is almost equal to S1.

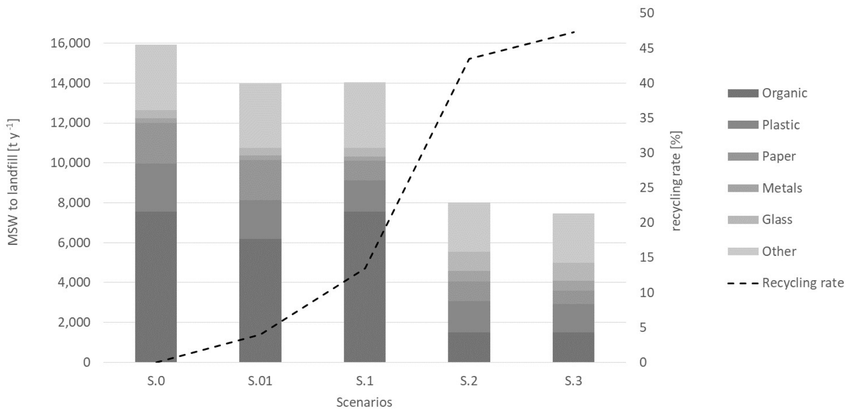


**Figure 4.21:** Amount of MSW disposed of to the sanitary landfill and recycled per MSW fraction and scenario.

Better results are obtained through the implementation of OFMSW door-to-door selective collection. It allows the interception of greater quantities of MSW generated. Therefore, in S2 the waste avoided to sanitary landfill is $7932.8t\,y^{-1}$ equal to 49.7%, reducing the volumes delivered to the final disposal site, reducing environmental impacts and generating a new waste economy. Finally, considering the flow of waste intercepted by the informal collection, a slight increase was obtained compared to S2, achieving to reduce up to $8476.4t\,y^{-1}$ of MSW, equal to 53.2% of the total waste generated. Therefore, the inclusion of informal collection leads to a reduction of landfill waste equal to $543.6t\,y^{-1}$ compared to S2, contributing to boosting the recycling rate to about 3.5%.

**Distances traveled**

The analysis of the collection routes allowed assessing the travel distances and the amount of waste collected by each compactor truck. The routes obtained assessing the MSW collection by mixed containers are reported in Figure 4.22.

The sum of the distances traveled for the ten routes necessary for emptying the mixed containers every three days (Friday and Monday collection) is equal to 90.8km, while seven routes are necessary for the collection every two days, for a total of 67.7km. To this path, it is necessary to add the distance of 10km that has been assumed between the study area and the final destination (treatment plant or final disposal). Therefore, in the collection carried out every three days the emptied volumes are equal to $201.6m^3$ covering a total of 290.8km, while in two days, $134.4m^3$ of MSW are collected, with seven routes and 207.7km traveled. Considering an average speed of $10 - 15km\,h^{-1}$, three compactor trucks are required to collect these quantities, operating 10h a day and covering three to four transport routes each.

The analyses of the MSW collection routes were carried out for each scenario, in order to verify the km traveled annually. For S3 the contribution of the informal collectors was calculated in order to estimate the path reduction of the compactor trucks. Figure 4.23a shows the points where itinerant waste pickers work. In each of the 15 points, it was assumed that ten waste pickers work, each of which has an interception capacity of $23 kg\, d^{-1}$ approximately. Evaluating the quantities collected by the waste pickers within the buffers, it was possible to discretize between the area of influence within the neighborhoods, evaluating the amount of MSW collected and the unnecessary formal MSW containers. In Figure 4.23a, it is visible that 24 districts are interested, out of a total of 30 in the pilot area.

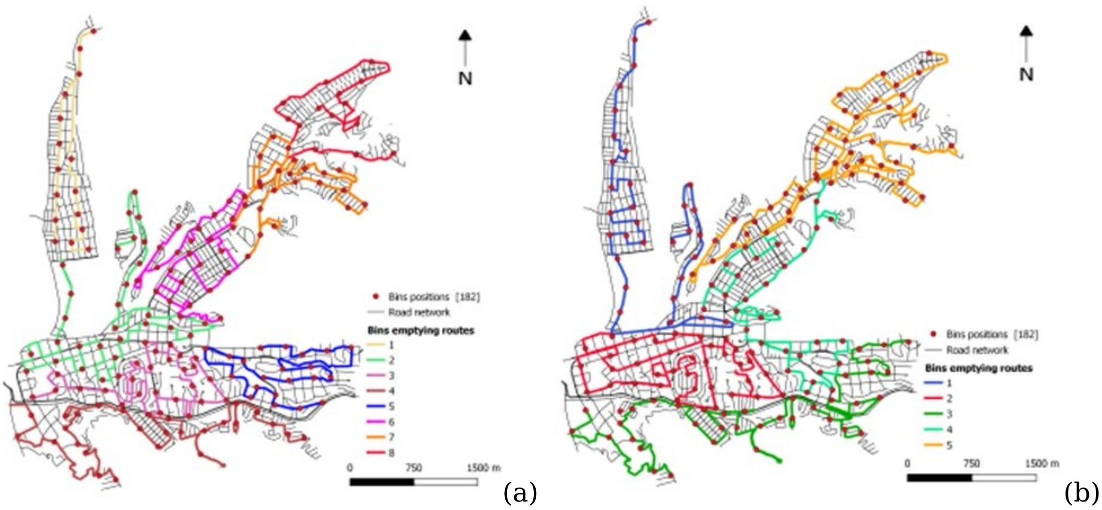


**Figure 4.22:** Containers emptying routes for S0 after (a) three days and (b) after two days of accumulation.

Figure 4.23b shows the reduction in the containers' number required in the pilot area. It was possible to reduce the number by about 97 units, including 28 plastic containers and 69 paper containers. From the figure it is visible that there are points in which the only container kept is the mixed one (in green). Comparing S2 to S3 it is possible to notice how the maximum volumes, as well as the total kilometers traveled by the collection trucks, decreased. Specifically, the total volumes of emptying after three days of accumulation go from a total of $207 m^3$ to a total of $184.3 m^3$, with an overall decrease of 10.9%. In terms of MSW fraction, the activity of the waste pickers reduces the MSW due to the interception of metals and glass, plastic and paper. In particular, there was a decrease of $143 kg\, d^{-1}$ in mixed waste, $704 kg\, d^{-1}$ for plastic and $1664 kg\, d^{-1}$ for paper and cardboard. Therefore, it is possible to notice that the formal collection should collect quantities of MSW lower than S1 and S2, since the mixed waste decreases by 1.3%wt, plastic by 10.6%wt, while the paper decreases for about 29.8%wt.

Thanks to the informal collection, a decrease in MSW collection routes was obtained. Figure 4.24 shows the average km traveled for each scenario. The tendency is that the distances traveled increase with the type of SC implemented. This behavior depends on the fact that, by separating waste in different fractions, a greater number of containers is required on the territory. Comparing S0 with S1 there is an increase of $14.645 km\, y^{-1}$, equal to 39.9%. With the door-to-door collection of OFMSW a further increase is obtained, achieving $31,355 km\, y^{-1}$, about 85.4% more if compared with S0. The trend change comparing S2 with S3. The reduction of road containers, made possible by the SC implemented by the waste pickers, allows reducing the annual path traveled by $2734 km\, y^{-1}$, equal to 7.4% or travel savings. It can be translated into the reduction of operating costs, environmental impacts, and traffic, improving the MSWM system.

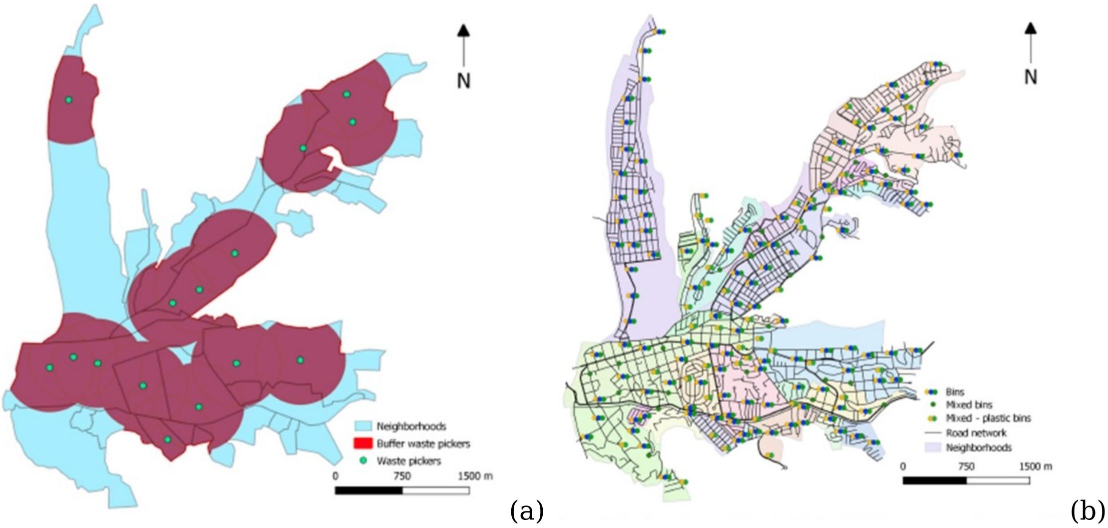


**Figure 4.23:** (a) Area of influence of the itinerant waste pickers and (b) location of the waste SSC reduced considering the SC activity implemented by the informal sector.

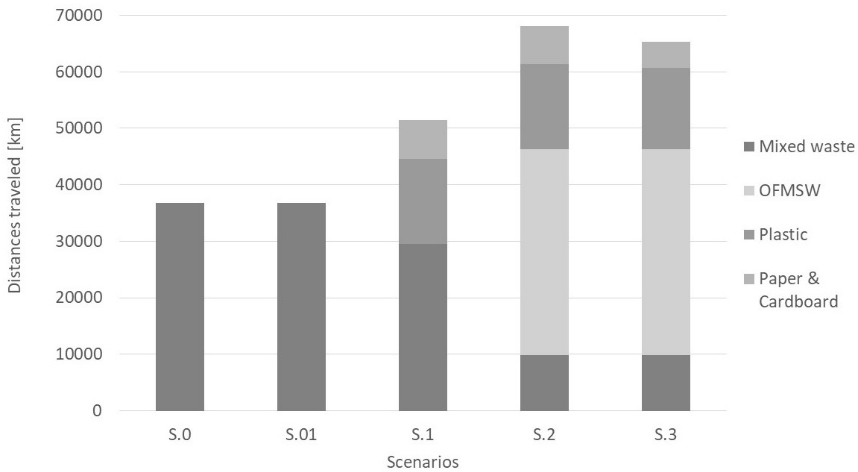


**Figure 4.24:** Distances traveled per scenario and MSW fraction collected, according to the analysis conducted with QGIS.

### Expenses of the scenarios

Figure 7 shows the expenses estimated for each scenario, divided by cost item. Specifically, the items that involve a municipal investment or direct cost are represented with positive values, while the gains deriving from the sale of the recyclable fraction are negative values. The required economic investment increase with the improvement of the MSWM scenario. Therefore, the scenario that involves lower investment costs is the mixed collection and final disposal to sanitary landfill, although it is the less affordable in an environmental point of view [99, 100].

The implementation of an MBT requires an investment cost for the construction of the plant. Compared to S0, the plant involves an increase in the final costs of about €334,000, considering the reduction of the final disposal costs by around 12.2% and the incomes for the sale of recyclable materials, gathering about €5000 per year. The operation of SSC in S1 involves an increase in costs for the purchase of road containers. This specific item increases by 48.5% of the total expenses. Moreover, the increase of the MSWM costs is associated with a 28.5% increase in transport costs for emptying operations, as obtained from routes calculated in the GIS environment. However, the income related to the sale of recyclable MSW is increased, for a total of about €236,000 per year, covering about 42% of the total costs. If compared to S0, S2 requires an increase in costs for 138%, about €500,000 per year. This is due to the implementation of a composting plant, the increase of the expenses for the MSW collection and for the containers. In this scenario, the sale of recyclable waste covers about 30% of the total expenses incurred by the system, therefore with lower economic advantages if compared with S1.

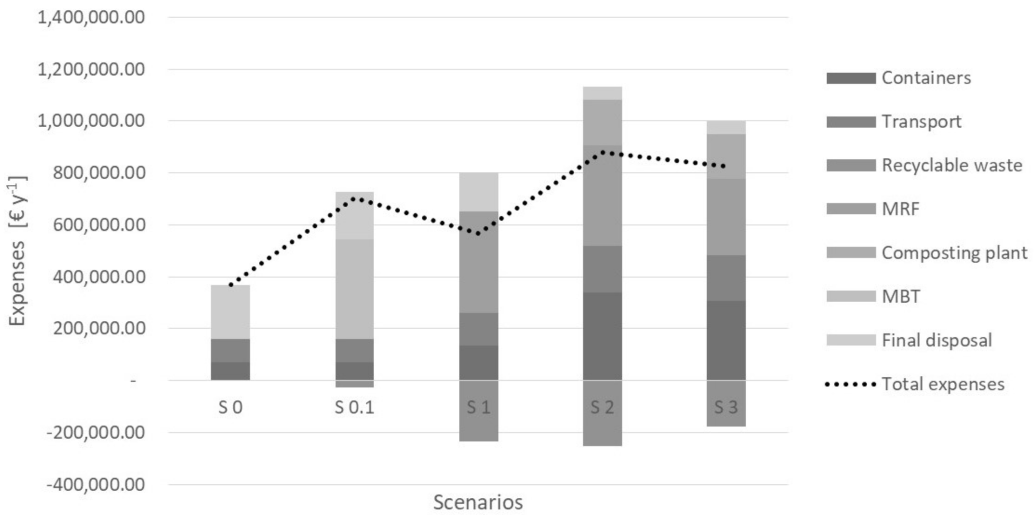


**Figure 4.25:** Yearly expenses per MSWM system. The negative values represent the incomes obtained by the sale of recyclable waste.

The last scenario involves the inclusion of informal waste pickers. If compared with S2, thanks to the reduction in landfill flows, use of containers and the collection routes, this scenario allows the reduction of the total expenses by 6.7%, equal to about €59,000, net of the revenues lost at municipal level for the sale of recyclable waste and recovered informally. Therefore, if compared to a complete SC system, this result represents an important data, demonstrating the advantage in waste pickers' inclusion for all the analyzed cost items.

### 4.3.8 Potentiality of the approach and implications of informal sector inclusion

The research conducted allowed the quantification of the benefits of the waste pickers' inclusion in an MSWM scenario that considers the SC of OFMSW and recyclable waste. This is the first attempt for providing data to policy-makers in order to justify the efforts for including the informal sector, besides social benefits. The approach provided values that indicate the affordability of their inclusion in terms of expenses, MSW collection and waste inflow into the final disposal site. The study conducted with QGIS3.8 can be replicated in the whole study area, as well as in other developing regions since the software is an open-access tool, reliable for every context where cartography and digital data are available.

Other studies were conducted in low-middle income regions using GIS, however, the scientific literature lacks the assessment of the parallel inclusion of waste pickers in the MSWM system. For example, in Kampala (Uganda), the use of the GIS tools provided indications for the reduction of the total travel distances, decreasing fuel consumption environmental impacts [101]. In Allahabad, India, GIS were used to providing details about the MSWM system, such as MSW generation, collection and transport [102]. In Mashhad, Iran, GIS was implemented for optimizing the MSW collection, reducing by 12.5% the daily collection tours, by 41.7% the crews and by 53% the total collection vehicle routing [103]. These case studies are located in developing countries, where the activity of the informal sector is persistent. However, within the analysis, the activity of the waste pickers was not involved.

Nevertheless, other research conducted in low-middle income countries suggests including informal recycling into the formal waste management system, as also stated in section 2.1 [104]. For example, in São Paulo, Brazil, cooperative of informal recyclers collect, select and transport recyclable materials, although in unsafe conditions [105]. In Johannesburg, South Africa, waste pickers have now become part of the MSWM system and are involved in MSW collection, sorting and recycling of recyclable waste [106]; however, they are not still recognized by the local government. In Jakarta, Indonesia, waste pickers deal with recyclable MSW in the final disposal site of the city, as daily, live-in and independent pickers. The authors strongly recommended their integration into the formal recycling system with new waste management policies [107].

In agreement with these studies, the results provided in this research strongly recommend the inclusion of the waste pickers in the MSWM planning, in order to consider the main benefits that they can provide to the local MSWM system and how the location of SSC, treatment plants and collection routes should consider their local activity. Moreover, results advise implementing GIS analysis in order to better understand the implication of waste pickers in the MSWM system.

### 4.3.9 Policy implications

The results provided can support the local stakeholders to consider the inclusion of the waste pickers and recycling shops in the MSWM system. The research provided first results demonstrating that waste pickers allow reducing the waste inflow into the final disposal site, improving the recycling rate of the city. Moreover, it allows reducing the management costs, in terms of MSW collection and treatment. The main issues are: how can they be involved? Are the citizens aware of these actors and do they agree on their inclusion? The research did not assess such issues, but suggest local stakeholders invest in efforts for understanding how waste pickers can be involved and accepted by the local population. The implementation of information campaigns is therefore compulsory, in order to explain the main pros and cons of the implementation of efficient MSWM systems, including high technological plants, new collection systems and facilities. The objective is to make visible the main barriers for its implementation, such as the financial sustainability and the investments required, in a context where the waste charges cover the 30-40% of the total expenses needed for S0.

Step by step approaches, modular facilities and technologies available locally, as well as the involvement of the local market, are the main recommendations that should be provided to local policy-makers, avoiding heavy investments for changing the system in short terms, increasing the risk of failure. The implementation of subsequent scenarios, as design in this paper, can be the right way for planning long term scenario, effective for improving the recycling rate of a developing city. Indeed, the message provided by the results obtained in this research is that MSW SC requires a long management process and significant investments, which should consider local opportunities and issues. Pilot plans and projects, supported by international NGO and funders can be one way for introducing step by step approaches, with participative activities useful for enhancing population awareness and the technical capacity of local policy-makers. These projects can start by the implementation of small scale MRF and treatment plants, the support in increasing public awareness and knowledge, the teaching to local engineers and technicians of problem-solving and project management. The first step can be the inclusion of the waste pickers and the implementation of local simple technologies, such as composting and MBT plants with manual selection and aerobic waste stabilization, taking into account that citizens' involvement is always the key issue [108, 109, 110].

### 4.3.10 Limits of the study and future improvements

The research has some limits that should be introduced in the next investigations. First of all, the costs analysis was implemented with the aid of international literature, due to the lack of data available locally. Secondly, the study did not consider the structure of the roads and the slope of the study area. However, these issues should be considered for optimizing the MSW collection routes. In the case of the city of Praia, Cape Verde, 3D analysis allows reducing 29% of distances and 16% fuel consumption if compared with 2D assessment [111].

The social acceptance, relevant subject for including the waste pickers in the formal SC system, cannot be considered in a GIS environment. Further studies should be implemented, in order to evaluate if the citizens agree with their involvement. This is also suggested by other authors; in Iran, GIS analysis was implemented, suggesting the application of proper use of social criteria for more realistic perception of the community and accurate results to use [112].

The analysis conducted is static, without providing fluctuations in MSW productions or variables in time and traffic. Other studies considered this issue, in order to provide more realistic assessments. In Vietnam, the GIS analysis was integrated with dynamic analysis, in which the impact of the traffic network on the work of MSW compactor trucks was including, finding an economic save of 11.3% [113].

Finally, the location of the MSW treatment plant and the current position of the MSW container was not involved. These issues can be introduced in the next study, in order to provide more specific assessments about the distances of the arrival points and the comparison with the current MSWM system. In Ghana, the location of MSW transfer stations was assessed with an MCDA and GIS analysis identifying suitable land areas, providing indications about the reliability of its implementation [114].

We strongly recommend the implementation of these methods, integrating all MSWM tools available and the issues afforded by other studies, taking into account the activity of the informal waste pickers, in particular in low-middle income countries. Future efforts should be focused on the introduction of these issues in GIS analysis in order to integrate the results obtained with the ones proposed in other researches. This will allow improving the MSWM planning of La Paz and other developing cities.

### 4.3.11 Remarks and considerations

MSWM planning is still a challenge in low-middle income countries due to the lack of know-how, financial support and data analysis. The informal recycling implemented by waste pickers is the main activity carried out for increasing the recycling rate of developing cities, although it is not considered by policy-makers and municipal authorities.

This section introduces a method for assessing the positive economic and managerial impacts due to the inclusion of the informal waste pickers in the MSWM system of La Paz. The use of GIS allows demonstrating the main advantages of their inclusion in terms of reduction of MSW collection routes, SSC, and investment costs. Moreover, informal activities allow increasing the recycling rate, boosting the circular economy principles. In particular, the research demonstrated that, if compared with a complex SC system, the inclusion of the informal recycling allows reducing the MSWM expenses of about 10%, increasing the recycling rate of about 3.5%, and reducing the distances traveled by compactor trucks of about 7%.

These results demonstrate the importance of the inclusion of the informal activity within MSWM planning. Though waste pickers are not formally involved in MSW collection and treatment, their activity is always present. Such issue should be highlighted to local stakeholders, in order to enhance the awareness of authorities in implementing integrated assessment in GIS environments, considering the activity of the informal sector and developing new policies and actions for valorizing local opportunities and practices.

In conclusion, this research provided preliminary results of the importance of the inclusion of the informal sector and the implementation of SC in developing cities. Economic barriers are always present in these contexts, while international cooperation and funds can support developing cities in implementing pilot projects, in order to improve local awareness and knowledge about environmental issues. The inclusion of waste pickers is strongly recommended since they implement local sustainable collection and management activities, economically viable in areas where the risk of investments is too high for being introduced in municipal policies and actions. Long term MSWM plans should be introduced, with step by step approaches for valorizing the circular economy activities just in place, in areas where sustainable development is still a challenge.

## 4.4 Introduction of SC systems: a pilot project implemented at the University

This research refers to the article *Selective collection of recyclable waste in Universities of low-middle income countries: lessons learned in Bolivia* (Ferronato N., Guisbert Lizarazu E.G., Velasco Tudela J.M, Blanco Callisaya J.K., Preziosi G. and Torretta V) submitted to the *Waste Management* Journal and currently under review (Major revisions).

### 4.4.1 Introduction

The CE and SC should be supported by the University, which is an important actor for introducing a sustainable future [155, 152], Globally, the “greening academia” is a topic of interest for improving sustainability, since university campus can be considered as small cities [117, 118].

In México, at the Azcapotzalco campus of the Universidad Autónoma Metropolitana, a SC plan was implemented for reducing the amounts of waste delivered to the formal collection system and improving recycling. In three years, the University sent to recycling about $2.2t$ of glass, $2.3t$ of plastic bottles, $1.2t$ of Tetrapack packages and $27.5kg$ of aluminum cans, involving the whole community [119]. In Brazil, at the University of Campinas, a continuous improvement cycle was implemented for designing a SWM program, introducing waste minimization campaigns, which brought the 16.5% of improvement in the SC system implemented [120]. Always in Brazil, a permanent selective collection program was implemented at the Federal University of Itajuba, finding that the 90% of the recyclable waste was sent for recycling, reducing the greenhouse gas emission of about $-7tCO_2$, saving about $1424.60kWh$ of energy [121]. Therefore, the implementation of SC at University campus, introducing sensitivity and information campaigns, allow reducing environmental impacts through recycling.

In this section, the implementation of a SC system at the UMSA is presented. This part of the research would be a reference for other similar contexts for providing a methodological approach based on scientific analysis for introducing SC at University campus, where the system should start from zero.

This research contributes to the scientific literature for assessing the main strategies for improving sustainable development in low-middle income countries. Therefore, the novelty of this part of the research is the implementation of methods for implementing and assessing recyclable waste SC systems in University campus of low-middle income countries.

The recycling scheme was assessed and implemented step by step, measuring the amount of waste provided to the formal recycling chain and the improvement of students’ awareness about recycling. The positive impacts of the project are measured by questionnaire surveys and by the analysis of the waste fractions collected, providing indications about the improvements obtained in a SC project started in in 2016 and implemented at the end of March 2019.

The approach is replicable in other low-middle income countries, where a formal or informal waste recycling system is just in place and where financial sustainability is low. The general objective is to support the implementation of the SDGs and the GWMG at global level, with a particular focus in low-middle income countries, following the principles of the CE and sustainable development.

### 4.4.2 Methods - Approach of the analysis

**Study area: UMSA – Faculty of Engineering**

The Faculty of Engineering of the UMSA is an academic unit consisting of eight careers and eleven institutes. In 2015, the number of students forming part the Faculty of Engineer were 7830. The study was carried out in the main building of the Faculty which hosts the largest university population. The building is composed of offices, administrative areas, libraries, classrooms, great halls, canteens and free areas for the students and consists of seven floors, a ground floor and a basement, where about 730 students study every day.

The waste collection service implemented in the building counts with six operators distributed within the floors, responsible for collecting waste and cleaning the areas of the university. In the corridors, there are tanks where all types of solid waste (classified as MSW) from various generators (students, professors, administrators, etc.) are deposited. These bins are not properly identified, they are not well located in areas where there is a greater requirement due to the numerosity of people and there is no SC system in place. At the end of the daily cleaning activities, the waste is collected and stored in black plastic bags, temporarily disposed in the same buckets, as well as in the corridors or inside the bathrooms, until filling the bags, to then moving them to the main door, where the MSW is then delivered to the municipal collection service.

Therefore, until 2018, the Faculty of Engineering did not supported the SC system implemented by the municipality and did not implemented recycling campaigns, as well as the other Universities of La Paz. However, the will of the UMSA is to implement a SC for complying with the regulation and the municipal SC system implemented in 2018.

**Overview of the SC system**

The project for introducing the SC system at the University was called P-UMSA-recycle. The translation of the acronym from Spanish is “for a better environmental sustainability – recycle”, in addition to be the acronym of the university. The implementation of the system was divided in five main steps: (step 1) preliminary analysis of the MSW management system, applied between 2016 and 2018, (step 2) following of the administrative pathway, (step 3) inclusion of the stakeholders (students, cleaners, administrative staff, professors, Directors of the careers and technicians of the local government), (step 4) starting of the process and (step 5) final evaluation. The scheme of the steps is painted in Figure 4.26. The specific objectives of the projects were: introduce a “green behavior” among the students; support the local Government in implementing the SC system of recyclable waste (plastic, paper and cardboard); reduce the environmental impacts of the University.

The project UMSA – recycle was implemented in cooperation with the UMSA – Faculty of Engineering, the local Government, the University of Insubria (Italy), Department of Theoretical and Applied Sciences, the University of Trento (Italy), Department of Civil, Environmental and Mechanical Engineering, and The Rotary Foundation. The local Government approved the system, as well as collected the waste selected and supported the information campaigns. The Italian Universities and The Rotary Foundation supported the implementation of the system and its planning. Moreover, the local mass media were included, such as newspapers and local televisions, for informing the population about the implementation of the SC system.

*Step 1: First analysis*

The first step of the project is the assessment and quantification of the waste fractions produced at the building of the Faculty. The analysis was implemented from March to July 2016, in order to assess how much recyclable waste is produced and compare it with the amount of waste effectively selected after the project. Then, a questionnaire survey was submitted to the students of the Faculty, in order to evaluate their behavior, knowledge and opinion about the MSW management system implemented at city and University level. The survey was conducted in January 2018, for a total of three weeks, required for providing the questionnaires and assessing the results. Finally, such information was collected for planning the SC system, providing a preliminary planning sheet to the local authorities.

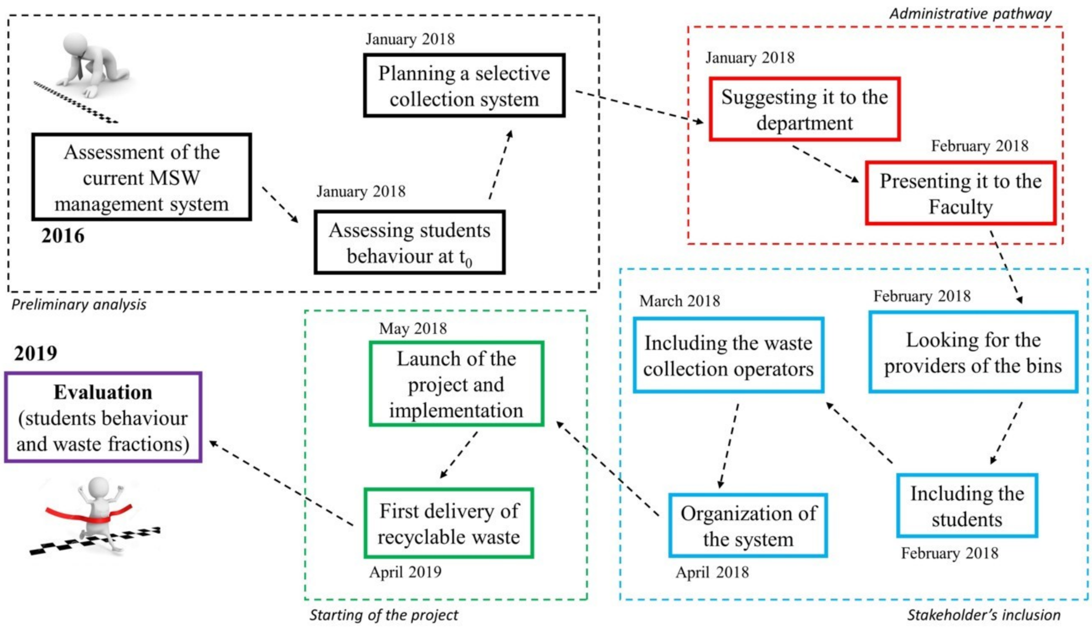


**Figure 4.26:** Scheme of the steps for implementing the SC system at the university.

*Step 2 – 3: Administrative pathway and stakeholder's inclusion*

The second step is the submission of the preliminary project to the authorities of the University. It requires a few months for its presentation and approval. It was submitted in February 2018 and finally approved in March 2018, making possible its implementation thanks to the use of University finances (although limited) for the purchase of the bins and the information material.

After the approval, the project was presented to the cleaners and to the students (step 3). The cleaners should know how, where and when the recyclable waste should be collected and delivered. Moreover, they should recognize the main advantages of the process, also for their daily work. The students were included by the introduction of a group of volunteers called "young waste innovators", that allow the implementation of the project and its diffusion among students and professors. Their activity at the University provided the information material, making a Facebook web-page (called *Proyecto UMSA-recicla*), and supported the implementation of seminars and conferences about the topic. Moreover, information campaigns were organized thanks to their assistance (step four). At the same time, formal waste bins providers were searched: it is not a simple activity in Bolivia, where the main bins sellers are informal, whereas the University required formalize the acquisition of the bins. Therefore, a few months were necessary also for this action.

Finally, the system was organized and planned in cooperation with the local Government – Secretary of Environmental Management. It was accorded that one day per week the waste should be collected (every Thursday) with yellow bags for the recyclable materials provided by the same Secretary. The yellow bags are returned every time that the bags would be delivered full of waste; a register is completed both by the University and the Government for assessing the waste quantity and the number of yellow bags delivered per week.

*Step 4: Starting of the project*

The project was inaugurated at the end of April 2018 with a formal event where the local televisions and the newspaper were present for broadcasting it to the population of La Paz. The bins (yellow for plastic and blue for paper and cardboard) were located in four areas of the university (Figure 4.27). Totally, eight bins of 220 L were available for the collection, covering about 30% of requirement of the whole building. However, due to administrative issues and local political changes, the SC system started only at the end of March 2019, mostly one year after the launch of the project, and the first yellow waste bag was delivered in April 2019.


**Figure 4.27:** SC bins located at the University.

In parallel with the implementation of the bins, information cartels were hanged above the bins, indicating which type of waste is collected, the best practices that could be applied, the definition of SDGs, CE and environmental sustainability and the main objective of the project. Five information campaigns were organized during the month before the first delivery of recyclable waste, with face to face explanations of the project: about 900 students were informed thanks to the support of the volunteers. Moreover, seminars and courses were organized for free for the students interested on the topic, with thorough explanation of concepts like life cycle of waste, waste treatment technologies, environmental contamination due to waste mismanagement and informal recycling. About 150 students participated in the courses and seminars.

These activities were the base for informing the students and the community about the main advantages of the implementation of the project and of its start. To date the system is implemented in about one third of the structure, and every week the waste is delivered to the local Government and recycled.

*Step 5: Evaluation of the system*

For assessing the compliance of the collection system, two indicators were implemented: the first, the analysis of the waste fractions produced and its comparison with the theoretical quantities generated at the university; second, the opinion and knowledge of the students about the MSW management system, comparing the results of the questionnaire survey implemented in 2018 with a new survey implemented in April 2019, one month after the delivery of the first yellow waste bag. Indicators are necessary for planning and implementing SC programs in order to support decision-making, and to adopt corrective actions, providing data to the users, comparing, classifying and prioritizing programs [122]. Therefore, two analysis were implemented in April 2019 for the assessment of the positive impact of the project: the analysis of the waste fractions and the questionnaire survey submitted to the students.

### 4.4.3 Methods - Analysis of the waste fractions

**A. Before the implementation of the project**

The waste characterization was programmed during one week of April 2016, guaranteeing the full operation of the institution. The sampling week was carried out with the participation of the cleaning staff during six working days from Tuesday $4^{th}$ of April 2016 to Monday $11^{th}$ of April 2016. For the analysis, plastics bags of 220L, a balance with accuracy 0.1kg and personal protection equipment were used for selecting and weighting the waste.

The waste was collected from academic areas (classrooms, refreshment areas, corridors), laboratories (only MSW and WEEE), bathrooms, the library, administrative areas (offices and congress areas) and the canteen. Laboratories, bathrooms, and the library are considered together with the academic areas since the waste collection system store these quantities together.

The bags collected during the week were weighed daily, while the waste was characterized one time for each source: academic areas, canteen and administrative areas. At the same time, the already classified by-products were weighed separately with the same balance with sensitivity of $0.1kg$ and the results were recorded on an excel form, with the purpose of determining the composition of each of the by-products. The materials assessed were classified in 10 groups: plastics (PET, PEHD, PELD, PP, plastic bags), paper and carboard, glass, metals (ferrous and non-ferrous), organic waste, WEEE, hazardous waste (piles and batteries), infectious waste (dirty toilet paper), inert (ceramic) and others non-recyclables (non-recyclable plastic, poly-laminates, rubber, wood, dirty paper, tissues, textile, sponges).

The average generation of solid waste and the students who were present in the structure allow determining the values of the generation per capita. Moreover, the data obtained could be used for assessing the amount of waste generated per month and per year, comparing the results obtained after the project UMSA-recycle.

**B. After the implementation of the project**

After the implementation of the SC system, a waste characterization was carried out. The aim was to assess the amount and percentage of rejects detectable and quantify the recyclable waste delivered to the formal MSW collection system. The analyses were carried out one time per week for one month, for a total of four analysis.

The characterization was carried out for the waste available in the recycling bins. Therefore, the fractions assessed were PET, PEHD, PELD, PP and plastic bags for the yellow bins, and white and colored paper, cardboard and cardboard for packaging for the blue bins. Moreover, the presence of fluids was also assessed. The recyclable waste was characterized and weighted with a balance with sensitivity $0.1\ kg$. The analysis was carried out every Wednesday evening, before the delivery of the waste to the formal SC system.

The results obtained were compared with the ones obtained with the characterizations implemented in 2016 for indicating the percentage of waste collected in comparison with the ones theoretically generated at the building. The comparison allows obtaining an indicator of the compliance of the SC system and of the users, as well as the positive impacts of the project implemented.

### 4.4.4 Methods - Questionnaire survey submitted to the students

**A. Questions and factors analyzed**

The use of questionnaires surveys and interviews is implemented in many case studies for assessing users' or population awareness, willingness to recycle and knowledge about environmental themes [123, 124, 125]. The objective of the survey implemented in this research was to assess two main factors: The approach that the students followed for supporting the MSW management system of the city (formal and informal), and their SC behavior at the University; The improvements of the students' behavior after the implementation of the project UMSA - recycle as indicator of the positive impacts obtained thanks to the new management system.

For obtaining data about the general behavior of the students, the questionnaire was divided in four main parts: the first for assessing the characteristics of the respondents; the second for assessing the MSW SC behavior at home and the general perception of its usefulness for reducing environmental impacts; the third for analyzing the SC implemented at the university; and the last for measuring the knowledge about MSW (Table 4.10). Totally, 15 questions were submitted, following the indications provided by previous studies [19]. The subjects of the questions were introduced in the sensitivity campaigns and seminars provided to the students during the year of the project UMSA – recycle. Therefore, the questionnaire was useful to assess the extent of diffusion of the information provided.

| Aspect | No. | Question | Choices for each question (A) |
|---|---|---|---|
| | | **Green points** | |
| General information | Qi | Age | 19-20; 21-22; 23-24; 25-26; 27-28; >28 |
| | Qii | Gender | Male/Female. |
| | Qiii | Department | Environmental, Civil, Electric, Chemical, Industrial and Materials Engineering |
| | Qiv | Semester | 1st to 10th semester |
| Implementation of the MSW SC | $Q_1$ | In your opinion, how much useful is the SC of the MSW? | It is not 1 – 5 It is very useful |
| | $Q_2$ | Do you think that the SC could reduce the contamination of the environment? | No 1 – 5 Yes, very much |
| | $Q_3$ | Do you implement the SC at home? If yes, how much MSW do you select? | I do not, I select a few fractions, I select more than the half of the waste that I produce, I select most of the waste that I produce, I select all the waste that I produce |
| | $Q_4$ | To whom do you deliver the selected waste? | I leave it on the road, I sell it, I waste it in the mixed containers, I deliver it to the green points or selective containers, others (reuse at home, compost at home. . . ) |
| | $Q_5$ | Do the waste pickers collect the waste in your neighborhood? | I do not know, never, sometimes, often, mostly every day |
| | $Q_6$ | Do you know the “Green points” for the municipal SC of the waste? | Yes, No |
| | $Q_7$ | Do you use the “Green points” for the SC of the recyclable waste? | Yes, No |
| SC at the University | $Q_8$ | Do you do the SC at the University? | No, never 1 – 5 Yes, always |
| | $Q_9$ | How much would you help with your will to improve the SC at the University? | Nothing 1 – 5 Very much |
| | $Q_10$ | How satisfy are you of the collection system implemented at the University? | I am not satisfied 1 – 5 Very much |
| | $Q_11$ | At the University, do you know about the implementation of information and sensitivity campaigns about recycling? | I do not know, Never, Sometimes during the last year, Often during the year, Mostly always every year, Always during the years. |
| Knowledge about solid waste | $Q_12$ | What is compost? | A container for the SC, A chemical product, a type of manure, I do not know |
| | $Q_13$ | In your opinion, which are the MSW fractions that cannot be recycled endlessly? | Glass, Can, Paper, I do not know |
| | $Q_14$ | In your opinion, in La Paz, how much solid waste is produced per capita? | 60g, 0.6kg, 6kg, I do not know. |
| | $Q_15$ | What are the SDGs? | An environmental policy introduced by the local Government of La Paz, International objectives for sustainable development for protecting the environment and end poverty, Objectives of the Bolivian Development Ministry introduced for reducing the poverty within the country, I do not know. |

**Table 4.10:** Questionnaire submitted to the students of the Faculty of Engineer of the UMSA..

**B. Method of the submission and number of students interviewed**

The questionnaires were provided to the students taking into account the gender, semester, career and age. The questionnaires were submitted with two methods: the first one, in the classrooms before the lessons, while the second online, sending the questionnaire by mobile phone. These two methods were the only available for submitting the surveys in order to obtain a random sample with a snowball sampling method.

The classroom where the questionnaires were provided were choose in function of the availability of the professors, the number of students, the semester of the course and the career. In particular, five classrooms were considered for both surveys. About 170 questionnaires were provided with this method in each period. The questionnaires online, instead, were submitted with the aid of the students, who sent the questionnaire by mobile phone to their friends; the questionnaires were implemented in Google modules. About 130 surveys were obtained with this method. The responding rate are not available in in this case since the number of forms sent online were not available, while the questionnaires provided within the classrooms were all returned.

The first survey round was implemented in January 2018, in order to assess the opinion and knowledge of the students before the implementation of the project ($t_0$). The second survey was implemented in April 2018, after starting the SC system.

The population size of the studies was calculated to obtain a confidence interval (CI) of 5.5 in the worst case of respondent (50% in binary answers – i.e. Yes/No), with a confidence level of 95%. This assumption was used in the sample size formula presented also in section 4.1 (equation 4.1.1 and 4.1.2). Therefore, 305 students were interviewed in the first and second survey round, for a total of 610 students.

The answers were mostly organized in Likert scale and in binary code (Yes/No) in order to assess the results. Before the submission of the survey, the main reason of its submission and the methods for its completion were explained to the students or wrote in the modules. Moreover, the questionnaires were provided to a group of 30 students, for finding errors and misunderstandings of the questions and answers. The questions are coded with the symbol $Q_j$, where j is the number of the question, from (i) to (iv) for the characteristics of the respondents, and from 1 to 15 for the main questions.

**C. Statistical analysis**

The statistical analysis was carried out with the software R-studio 1.1.463. The t-test was implemented between the results obtained in 2018 and 2019 in order to evaluate the significance of the changes in opinions and knowledge of the students after the implementation of the information campaigns. A p-value minor of 0.05 was considered significant ($p<0.05$). The students interviewed in 2018 are the control group, while the ones interviewed in 2019 the experimental group. Finally, the Pearson's correlation analysis was implemented for assessing the questionnaires submitted in 2018 and 2019. The correlations were compared between the two years for assessing its trend, while a significance minor of 0.05 was used for its relevance. The chi-square analysis was implemented among the questions correlated with the person's test, for assessing its dependence or independence

### 4.4.5 Results - Quantities of waste generated at the University

#### Fractions theoretically produced at the University – before the project

The results of the analysis of the waste produced before the implementation of the SC system are reported in Table 4.11. The amount of waste totally produced in a day is equal to $36.1 \pm 9.2\,kg$, mostly generated at the academic areas, with a theoretical waste production per year (200 working days) equal to $7.2t$. The total daily generation is quite constant during the week, with a reduction during the Saturday, when the administrative activity is not working, and with an increasing during the end and the start of the week.

| | Samples | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Tue 05-04-16 | Wed 06-04-16 | Thur 07-04-16 | Fri 08-04-16 | Sat 09-04-16 | Mon 11-04-16 | Mean ($kg\,d^{-1}$) | St. Dev. |
| Academic areas | 22.1 | 16.1 | 23.8 | 22.3 | 19.4 | 29.4 | 22.2 | 4.5 |
| Canteen | 6.0 | 13.1 | 6.2 | 15.1 | 0.0 | 7.3 | 8.0 | 5.4 |
| Administr. areas | 6.4 | 7.6 | 6.7 | 7.5 | - | 7.4 | 7.1 | 0.5 |
| Total | 34.6 | 36.8 | 36.8 | 44.8 | 19.4 | 44.1 | 36.1 | 9.2 |

**Table 4.11:** MSW generation at the University, assessed for one week.

Therefore, taking into account that on average about 730 students are present in the building every day, the potential generation per student is $49.5g\,d^{-1}$. This data can be considered for making general assessment of the amount of waste produced in the Faculty of Engineering of the UMSA and in the Universities of La Paz during a year, which count about 70,000 to 80,000 students. Considering that the University is open about 200 days per year, a student can generate yearly about $9.9kg$. Therefore, all the Faculty of Engineering could generate about 77.5 tons of waste per year, while all the Universities of La Paz can generate about $693\,t$ to $792t$, equal to the MSW generate in La Paz in one day. Therefore, at the building considered for the study, the amount of waste produced is about 10%wt. of the total theoretically generated at the Faculty of Engineering.

The analysis of the characterization of the waste are reported in Table 4.12. The main waste fractions generated at the University are recyclable plastics and organic waste, followed by paper and cardboard and other non-recyclables. The organic fraction is mainly produced at the canteen, while the administrative areas are the main generators of paper and cardboard. A relevant waste fraction generated is the infectious waste (dirty toilet paper), that is very hazardous to manage and transport for the MSW management system of La Paz, since the MSW is collected with scarce precautions.

Interesting is to notice that the inorganic recyclable fractions are about 37.3%wt. The ones currently collected and recycled by the formal recycling sector are plastic, paper and cardboard, the ones also collected by the project UMSA – recycle. However, before the project, these amounts were sent to final disposal. It means that the building produce about $7.7kg$ of plastic waste and $3.6kg$ of paper and cardboard per day, equal to $184.8kg$ and $86.4kg$ per month, respectively. These fractions could be recovered for recycling and delivered to the formal recycling chain. Moreover, these quantities can be used as reference for the SC system in order to assess the amount of waste intercepted by the system.

| Waste Fractions | Academic areas [%] | Canteen [%] | Administrative areas [%] | Total [%] |
|---|---|---|---|---|
| Plastic | 23.7 | 15.2 | 20 | 21.4 |
| Paper and cardboard | 9.3 | 1.6 | 23.3 | 10 |
| Glass | 5.2 | 4.9 | - | 4.3 |
| Metal | 0.5 | 6.4 | 1 | 1.9 |
| Organic waste | 32.8 | 67.2 | 17.9 | 37.3 |
| WEEE | 2.4 | - | 17.7 | 4.4 |
| Hazardous waste | 0.3 | - | 0.1 | 0.2 |
| Inert | 1.1 | - | 0.3 | 0.7 |
| Infectious waste | 13 | - | 6.7 | 9.3 |
| Others non-recyclables | 11.7 | 4.7 | 13 | 10.5 |

**Table 4.12:** Waste fraction produced at the University.

### Waste selected and delivered to the municipal SC system – after the project

The SC system implemented allows intercepting the first amounts of waste from the streams sent to sanitary landfill. The results of the waste analysis implemented during the first four weeks of the project are reported in Figure 4.28. The graphs report the total amount of rejects, liquids and recyclable waste delivered to the formal recycling system.

The plastic waste collected per week vary from $1.8kg$ to $5.6kg$, while the rejects from 23.1%wt. to 41.8%wt., which is a percentage of rejects higher if compared with high-income case studies, where about 16%wt. in Belgium [143] and 17.1%wt. $\pm 6.5$ in Spain [128] were found in packaging waste. The amount of paper and cardboard collected are grater and of better quality, varying from $4.2kg$ to $22.2kg$ of recyclable paper and cardboard and from 10.5%wt. to 45.5%wt. of rejects, similar with plastic waste. Therefore, after one month of implementation of the system, about $15kg$ of plastic and $37.1kg$ of paper and cardboard were collected and delivered to the municipal SC system. Compared with the amount theoretically generated at the building, the plastic collected is about 8%wt. while paper and cardboard 42.9%wt., suggesting that the selection of cellulosic fraction is easier for the students.

These data allow assessing the preliminary results obtained by the system. Although the quantities of plastic waste are low, the amounts of paper and cardboard could be considered satisfactory, taking into account the small extension of the SC system and the four weeks of implementation. Moreover, these analyses demonstrated the importance of the implementation of waste fraction analysis before and after the implementation of the projects, in order to provide indications about the results obtain during its application.

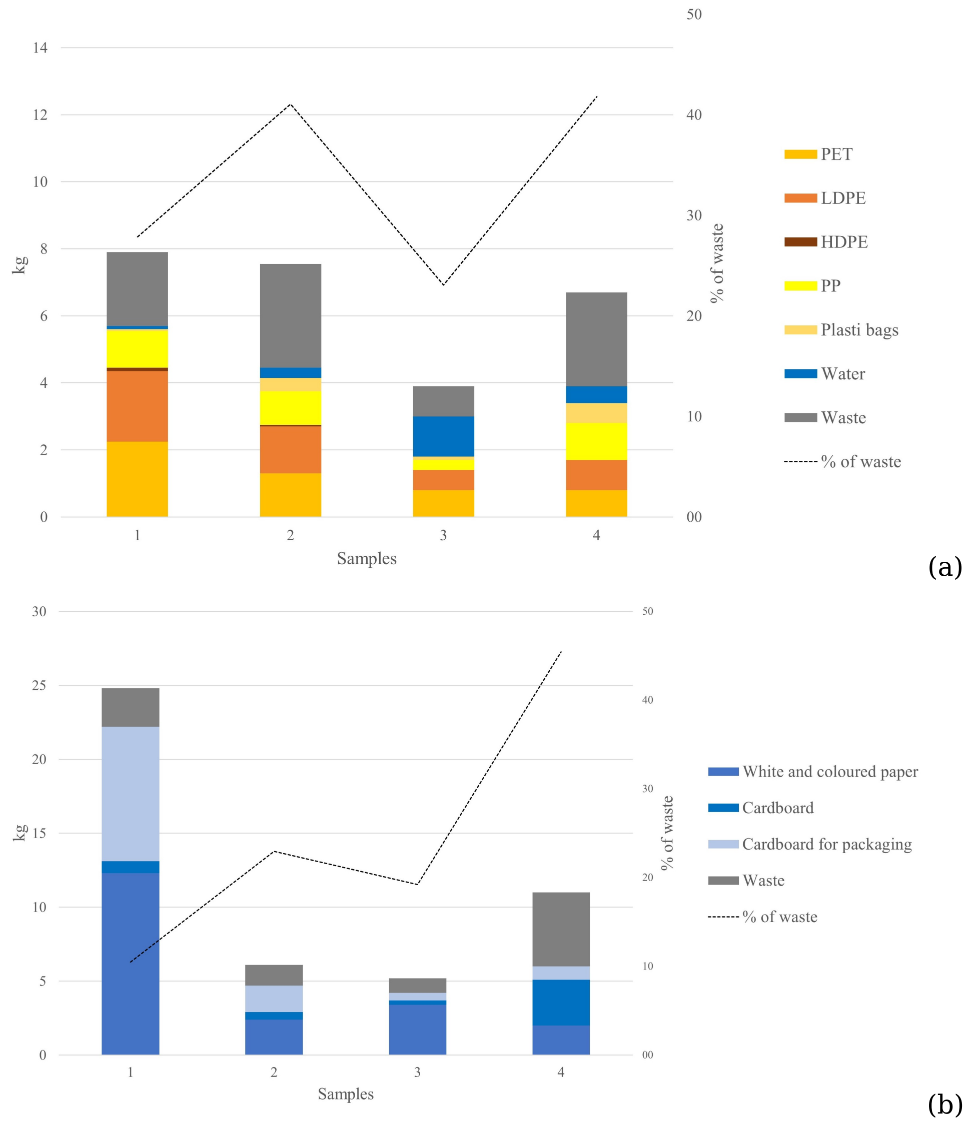


**Figure 4.28:** Analysis of the waste fractions generated in four weeks and collected in the selective containers for plastic (a) and for paper / cardboard (b). The dashed line represents the percentage of rejects detected in the SC bins.

### 4.4.6 Results - Answers of the questionnaires survey - before and after the implementation of the project

#### Sample distribution

The female interviewed were 46% in 2018 and 57% in 2019, with an average age of $22.1 \pm 2.9$ years old in 2018 and $22.9 \pm 2.7$ years old in 2019. Therefore, the sample is balanced in terms of gender and age. The careers are quietly different in the two years only regarding industrial and electric engineering, with 9% and 21% in 2018 and 23% and 3% in 2019, respectively. The others achieved similar percentages. Finally, similar are the semester followed by the students, with an average of $4.5 \pm 2.7$ in 2018 and $5.5 \pm 2.7$ in 2019. Therefore, the questionnaire surveys can be considered comparable.

**Implementation of the waste SC**

The results report the behavior of the students about the implementation of the SC of the waste at municipal level. For Q1 and Q2, the results obtained show a general aware about the usefulness of recycling, and its role for reducing environmental impacts. In particular, in both questionnaires, on average, the students considered useful or very useful the implementation of the separate collection of the waste ($4.7 \pm 0.6$ for both years), and they think that its implementation can aid the improvement of the environment ($4.8 \pm 0.5$ in 2018 and $4.7 \pm 0.7$ in 2019). These results demonstrated that the consciousness about the need to implement the waste SC is high.

This statement is supported by Q3, where the students should provide information about how much waste they separate. It is interesting that, for both interviews, less than 30% of the students do not implement the SC, while more than 15% select more than the half of the waste produced. In particular, the results of Q4 shown that 47.2% of the students in 2018 and 43.3% in 2019, sell the material selected to the informal sector. The different percentage obtained for Q4 is not significant ($t_{[608]} = 1.169$, p=0.24), therefore providing information about the constant and widespread delivery of recyclable waste to the informal recycling system. The constant activity of the informal recycling in the city is also demonstrated by the results of Q5, where less than 30% of the students do not know its activity in the city, while the other 70% confirm that the waste pickers operate in the neighborhood sometimes, often and in a few cases mostly every day (less than 4%).

The results highlighted the presence of an informal recycling system active in the city, with a relevant contribution of the students in its chain. While the formal SC system implemented in the municipality is mostly unknown, even if growing. Indeed, the results of Q6 underlined that only 26.2% in 2018 and 34.1% in 2019 knew the presence of the GP and separate street containers in the city. These little growth is statistically significant ($t_{[605]} = 2.122$, p=0.034*), demonstrating the positive effect of the improvements implemented by the local government in applying recycling plans, such as the recent allocation of selective containers in two neighborhoods of the city. However, only 46.3% in 2018 and 51.9% in 2019 of the ones that knows the formal recycling, use it for delivery the waste.

The comparison of the results of the two surveys provide two main information: Most of the students implements the SC of the waste, although providing it to the informal recycling chain; Though waste recycling is a new topic, it is just knowing by the students, while the municipal information campaigns improved the awareness about the presence of SC plans.

**SC at the University and knowledge about MSW**

The results obtained for Q8, Q9 and Q10 are reported in Figure 4.29, where the surveys implemented in 2018 and 2019 are compared. The results are of interest for evaluating the effect of the implementation of the recycling systems at the university, and the impact that it caused to the recycling behavior of the students.

The outcomes highlighted that the SC system implemented by the students at the University (Q8) improved considerably from 2018 to 2019, with an average of $2.3 \pm 1.2$ in 2018 and $3.0 \pm 1.3$ in 2019 ($t_{[600]} = -7.654$, p<0.05***), demonstrating the positive impact of the SC system. At the same time, the satisfaction of the students, about the waste collection service provided, was improved, with an average of $2.6 \pm 1.2$ in 2018 and $3.2 \pm 1$ in 2019 ($t_{[605]} = 2.122$, p=0.034*). This represent another positive indicator about the good impact of the new service provided for collecting the MSW. Finally, a statistically significant change was also obtained about the diffusion of information with sensitivity campaigns organized during the project (Q11). The result of 2018 was $2.4 \pm 1.2$, with the majority of the students (49.8%) that provided negative answers, while in 2019 the average response was $3.3 \pm 1.3$ ($t_{[604]} = -8.708$, p<0.05***), demonstrating that the diffusion of the campaigns achieved a good percentage of students.

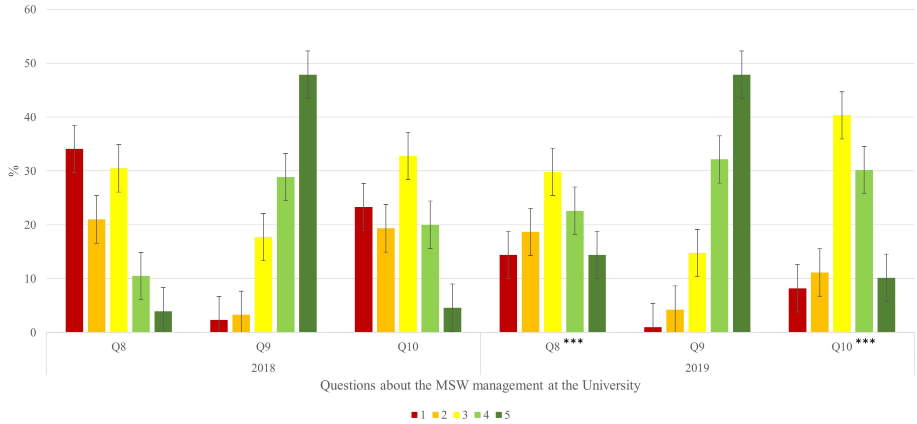


**Figure 4.29:** Results of Q8, Q9 and Q10 in 2018 and 2019. The statistical significance (p<0.05) of the improvements obtained after the project is reported with ***.

These results are supported by the improvements of the knowledge of the students about technical aspects of the MSW management. In Figure 4.30, the results of Q12, Q13, Q14 and Q15 are reported, comparing the responses of 2018 and 2019 and the progresses achieved after the implementation of the recycling system. Statistically significant developments were obtained for Q12 ($t_{[604]} = -8.708$, p<0.05***) and Q15 ($t_{[604]} = -8.708$, p<0.05***), although graphically it is visible an enhancement also for Q13 and Q14.

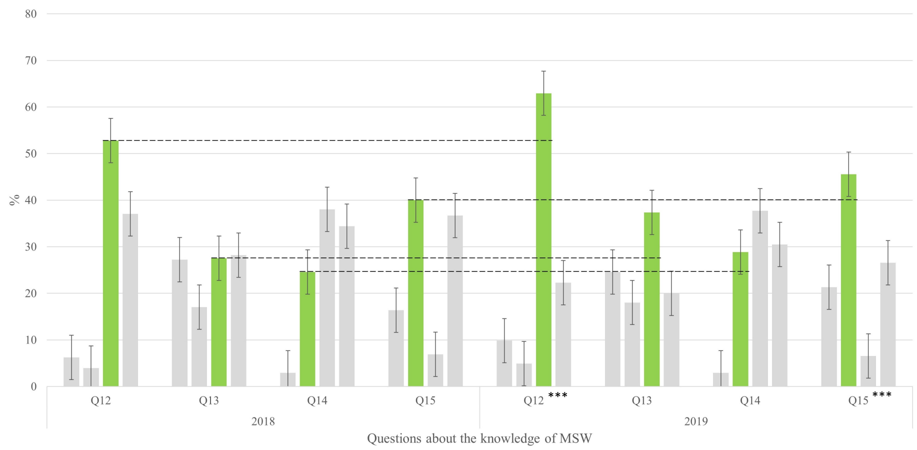


**Figure 4.30:** Results of Q12, Q13, Q14 and Q15, about the knowledge of the students in 2018 and 2019, with the improvements of the positive answers (in green) after the implementation of the project UMSA – recycle (dashed lines). The statistical significance (p<0.05) of the improvements obtained after the project is reported with ***.

These results provided again positive indications about the good compliance of the seminars and information campaigns implemented at the University, where these specific topics were taught, and therefore positive results of the project UMSA - recycle.

**Correlation relationship**

The Pearson's analysis was implemented in order to evaluate possible correlations among the results obtained (Figure 4.31). With a focus on 2019, the results highlighted that the separation of the waste at home (Q3) is positively correlated ($r = 0.167$, p=0.0035**) with the implementation of the SC at the University (Q8). It suggests that the students who just applied the waste selection at home are also inclined to implement the SC at the university, and vice versa, demonstrating that people's recycling behaviour depend also on institutions [126].

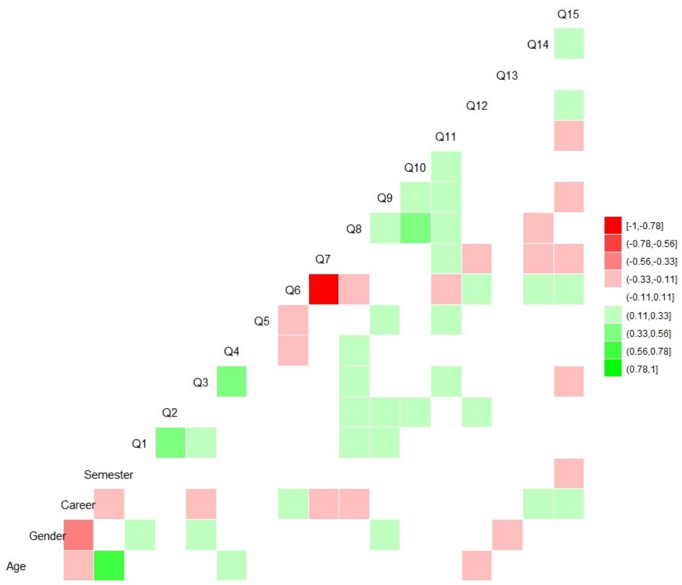


**Figure 4.31:** Correlation relationship of questions submitted in 2019.

At the University, who implements the SC (Q8) is more satisfy about the service provided (Q10), therefore with positive correlation between these two factors ($r = 0.341$, p<0.05***). Finally, who knows the presence of sensitivity campaigns and seminars (Q11), implements the SC at the University ($r = 0.314$, p<0.05***), is driven to improve the quality of the separate collection (Q9) ($r = 0.124$, p=0.032*) and is satisfy of the cleaning service provided ($r = 0.222$, p<0.05***). Therefore, for a University policymaker, the implementation of conferences, seminars and courses about environmental sustainability and recycling has many advantages, suggesting its implementation for improving the quality of the University environment.

About the knowledge, the students that know the SDGs (Q15), are positively correlated with the ones who know the presence of the municipal recycling campaigns ($r = 0.167$, p=0.0034**) and use the separate street containers provided by the local government ($r = -0.130$, p=0.023**) Moreover, right answers provided about the SDGs, are also positive correlated with right answers in Q12 ($r = 0.314$, p<0.05***) and Q14 ($r = 0.314$, p<0.05***), with also a positive dependence of the responses provided both for Q12 ($\chi^2_{[9]} = 60.654$, p=0.0036**) and Q14 ($\chi^2_{[9]} = 39.933$, p<0.05***). Therefore, the knowledge about a technical question is also positive correlated and depend of the good answer of another. In section 3.3.3 was underlined how the right responses also improved from 2018 to 2019, suggesting that the information campaigns and the seminars were useful for improving the knowledge and awareness of the students. If summed with the results of the waste characterization, these results suggest that the project UMSA – recycle had a positive impact on the students, with preliminary good results.

### 4.4.7 Challenges for the implementation of SC systems

The SC system achieved good results in terms of users' awareness and quantities of waste selected. However, many difficulties and barriers are still present. First of all, the political support and the continuity of the administrative system is difficult in these developing contexts in terms of implementation of environmental plans [129, 130]. Therefore, the financial support is not sufficient or always available for implementing the process in the whole areas of the University in short terms. The project has been implemented only in 30% of the building, with long terms for its implementation: acquisition of the bins, purchase of information materials, organization of seminars and sensitivity campaigns are the main activities that required financial support. The system should be implemented in the whole areas of the UMSA, although until now it was not possible: the political will is compulsory for its success.

The realization of the project UMSA - recycle demonstrated the good results in the implementation of the sensitivity campaigns, the seminars and the introduction of appropriate infrastructures (bins and information materials). Other studies underlines that the implementation of awareness campaigns is necessary for improving the results of a SC systems [131], and the results of the questionnaire surveys supported this concept. Periodic analysis should be introduced for assessing how the students perceived the changes or the improvements, since it represents a reliable indicator of the positive impacts obtained.

Although the amount of waste collected is quite low compared with the amount theoretically available at the University, about 8% of plastic and 42.9% of paper and cardboard, and the rejects percentage is high (about 10-40%), the results could be defined promising. First of all, the results demonstrate that it is easier to recycle paper and cardboard than plastic, due to the difficulty in assessing which type of plastic waste is recyclable or not. Secondly, it should take into account that the system was just implemented, and that the students, as well as the staff of the University, should better learn about the new system in practice. Finally, the SC system was not implemented in all the careers of the Faculty, therefore reducing the probability of interception of the recyclable waste generated. The reporting system organized in cooperation with the local government for assessing the weekly recyclable waste delivered will be useful for assessing the periodical fluctuation of the quantities collected. However, periodical waste characterization analysis should be carried out for analyzing the percentage of rejects.

### 4.4.8 Policy implication and future improvements

The project implemented allows demonstrating the potentiality of the introduction of information campaigns and the introduction of infrastructures for the support of formal SC systems. The same project allows suggesting which guidelines should be followed for introducing reliable SC systems in University campus of low-middle income countries:

- Pre-assessment of the system, before the introduction of the project. This action is imperative for providing reliable data to the policy-makers, explaining the importance of the implementation of such environmental actions:
- Cooperation with the stakeholders of the system. The collaboration with public actors, students and with the staff of the University allow introducing a system accepted by the same users, who will be the ones that should implement autonomously the SC system. A bottom-up approach is therefore compulsory, which can be supported by the organization of groups of volunteers;
- Introduction of sensitivity campaigns, seminars, conferences and information materials. It is imperative for two main reasons: explain the main pros of the implementation of the project, motivating the users to support the SC campaigns;
- Inform about the realization of the SC systems. The introduction of such actions is necessary for introducing a new awareness about recycling, changing the behavior also at municipal level;
- Generating indicators. It is the only way for demonstrating the good impact of the project to policy-makers and to the same users, in order to provide reliable data about which kind of impacts were generated thanks to the activities implemented.

If these five points are considered integrally, the implementation of SC systems could be introduced also in low-middle income countries, where environmental policies are still under development. The importance of its application could generate positive effects also outside the University, thanks to the transfer of behavior to the families and other social groups. It can spread the inclusion of the informal sector, practice just implemented in La Paz, and of interest at international level [132, 28, 133]. Moreover, the University can be considered as example for introducing recycling policies at municipal level, for supporting the formal or informal recycling chain, since the recyclable waste can be delivered both to informal operators or to the municipal collection.

The good results obtained by the project means the implementation of the same action in the whole UMSA, with further improvements at all Universities of La Paz. The same methodological approach could be implemented in other public or private areas of the city, where the development of SC schemes is required. Moreover, the project could be replicated in other context of Latin America, or in low-middle income countries where the starting from zero of SC systems do not allow a simple and effective introduction of recycling activities. Therefore, the system could be used and replicated for improving the CE in the developing world.

### 4.4.9 Remarks and considerations

The project demonstrated the main issues detectable in these contexts, such as the lack of awareness, financial and political support. However, it also demonstrates how the youngest are ready for implementing recycling and the principles of the CE, thanks to the presence of the informal sector, which support the growing of environmental behavior also in low-middle income regions. Indeed, the good results of the project could be due to the habit of the students to implement the SC of recyclable waste at home for selling the materials to the waste pickers. Therefore, the support of formal or informal recycling system can be a lost opportunity for Bolivia and similar low-middle income countries.

On one hand, the results suggested that the study of the system should proceed further in order to assess the recyclable waste gathered during the months. Moreover, a second assessment should be implemented after the introduction of the system in the whole university, in order to compare the past and future amounts of waste selected. Finally, seminars and information campaigns should be constantly organized, in order to improve the awareness and knowledge of the students about environmental themes.

On the other hand, the positive results obtained suggest replicating the system in other contexts (national and international) in order to improve the recycling chain of a region, supporting the local economy and reducing environmental impacts, especially due to the uncontrolled final disposal. Therefore, this research can be considered as reference for implementing the same guidelines in other University campus, with a step by step process, that could require various years for its implementation.

On balance, the study demonstrated how difficult is the introduction of SC systems due to various factors: political will, financial support and lack of awareness. However, its introduction can produce positive effects both at University and municipal level, supporting the activity of the informal or formal recycling sector, spreading sustainability and environmental behaviors.

## 4.5 Hazardous waste streams: implementation of HWM indicators

This research refers to the article *Application of healthcare waste indicators for assessing infectious waste management in Bolivia - Waste Management & Research* (Ferronato N., Ragazzi M., Torrez Elias M.T., Gorritty Portillo M.A., Guisbert Lizarazu E.G. and Torretta V. - 2019) [1], presented at the $6^{th}$ international conference on sustainable SWM (Naxos - Greece - 2018).

### 4.5.1 Introduction

Healthcare waste management (HWM) in developing countries often represents a health and environmental concern due to its mismanagement [134, 135, 136] and lack of treatment [137]. The absence of no effective activities for HW minimization, separation, and recycling [138], and the low levels of training and consciousness of waste legislation [139], improve the spread of diseases [140], decreasing the quality of the service provided and the security of the operators [141].

The increase in using disposable medical products and the growth of the world population, contributes to the increase of HW generation [142], enhancing difficulties in waste management, particularly in low and low-middle income countries [143]. The factors that should be considered for estimating the generation rates of HW in hospitals are the number of bed [144], the amounts of occupied beds [145], and the income of the country [146]. In low-middle income countries, the range of HW generation could vary from $0.02$ to $3.2\, kg\, bed^{-1} day^{-1}$, since there is a huge difference among healthcare facilities in rural areas, towns, and cities [147]. Therefore, in low-income countries, the lack of data about the waste generation, the absence of programs for waste minimization, appropriate treatment, and trained personnel affect the HWM planning [148, 149].

The application of management tools for planning HWM solutions is of great importance. Barbosa and Mol introduced a set of indicators in order to quantify the HW produced in a Brazilian public institution for assessing the quality of the HWM system [150]; Tesfahun et al. introduced a prediction model for measuring the HW generation rate for proper handling of infectious waste [151]; Moreira and Günther used a form-based checklist, in parallel with quantitative analysis of the HW, in order to assess the quality of the HWM system in a healthcare facility in Brazil [152]; Caniato et al. introduced a set of parameters for reviewing the scientific literature about HWM systems [153].

These management indicators were introduced in order to assess the HWM systems using quantitative and qualitative data. However, the indicators reviewed are limited to approaches suited specifically for the study areas investigated or related to quantitative assessments, providing restricted analysis. Other authors suggested that there is the need for holistic approaches and information platforms for the decision-making process in HWM [154], for improving scaled capacity building and public's awareness [155]. Therefore, the present study would contribute to the implementation of a holistic approach for HWM, based on quantitative and qualitative assessments, topic investigated in many contexts worldwide [156]. The aim is to propose an integrated tool suited for developing areas and replicable in other cities, in order to develop a novel and common method for comparing and commenting pros and cons of the HWM systems of low-middle income countries.

For evaluating the state of HWM system in an integrated way, an indicator set was developed and applied according to the management directives presented by the WHO in 2014 [157]. With the indicators developed in this research, five key areas of analysis were assessed, as suggested by other authors [158]: budget support, developing policies and legislation, technology and knowledge administration, treatment and final disposal issues, and quality of the collection and transportation system.

The application of the HWM indicators is introduced focusing on collection, storage, treatment, monitoring and staff awareness [159, 160]. The aim of the research implemented in La Paz is to introduce the management tool developed in this study for providing the results of a real case study, assessing the main pros and cons of the approach. Results are introduced thanks to the data obtained by fieldwork conducted from January to April 2019 at municipal level and in three public hospitals of La Paz.

Moreover, The indicator set is a tool developed in this research for assessing the needs and the main issues that should be solved in La Paz. The aim is to provide an method for providing reliable information about the main problems that should be addressed in projects for improving the HWM of the city.

### 4.5.2 Methods

**How to build the healthcare waste indicators**

The study introduces an integrated indicator set that was built in order to assess three issues:

- HWM in hospitals;
- HWM at municipal level;
- the quality of the data used for implementing the indicators.

These issues are of particular interest in the HWM system in developing cities [137]. The HWM indicators and criteria reported in the study are in agreement with the guidelines provided by the WHO [157]. However, the introduction of specific indicators for assessing data quality is specifically presented in this research and considered in function of the fieldwork in La Paz.

The starting point for the application of the indicators is to obtain local and current reliable data. Moreover, an impartial actor expert in the field of HWM should apply it. Local universities, international NGOs and the private sector should be involved, in order to build a multi-stakeholder and multi-disciplinary analysis. Therefore, the fieldwork and the cooperation with local partners is of utmost importance for completing the indicators, as well as the expertise of the indicators' users. The methodologies that should be adopted for completing the indicators are mainly four:

- interviews with local engineers, hospitals directors, nurses and waste operators;
- field inspection of the areas;
- assessment of local regulations and governance;
- review of local documentation.

In particular, the interviews carried out are structured in function of the indicators developed, assessing knowledge and practice of both health workers and medical staff. The submission of interviews to health workers is a method used in other case studies [161]; in this research, the indicators would provide a unique and integrated approach for its assessment, which can be replicable in other contexts. In this research, the indicators were developed and applied thanks to the cooperation between a local University and a foreign one, the collaboration of three hospitals of the city and the indirect support of an international NGO and the local municipality. In particular, the research implemented by a Ph.D. and a master degree in environmental engineering was compulsory for implementing the fieldwork and the indicator set.

The structure of the indicators introduced by Wilson et al. [162], for the assessment of the MSW management system in developing countries, was used and adapted for the specific analysis of HW. Such approach is similar with the one introduced also by Caniato et al., although it was implemented for a literature review [153], whereas in this research it is implemented for a real case study.

Each indicator set is divided into 5 to 7 criteria. Each criterion could receive a score from 0 to 20, in a scale of 5. The criterion is split into 5 sub-criterion, each of which refers to a score, function of the compliance of the HWM system. The sub-criteria have an explanation that provides an indication of an average situation that could be detected in a hospital (or in the municipality) concerning its compliance with the WHO directives. The lower score, or the first sub-criterion, describes the worst condition detectable, while the highest score, or the last criterion, contains the best situation. Details about the use of the criteria are provided in a user manual, which is not reported in this article. The descriptions of the criteria for providing the score were introduced thanks to the guidelines of the WHO and then adjusted in function of the field analysis implemented within the hospitals of La Paz.

The indicators are presented in percentage, from zero to 100%, by a radar scheme. The percentages are summed up in a traffic-light scale, in agreement with data in table 4.13. Five indicators are provided for assessing the hospitals of the city. The percentage obtained for the first five indicators allow assessing each hospital in the city. Therefore, the indicators should be implemented for a representative number of hospitals in order to well describe the HWM state at municipal level. In particular, for assessing the HWM system at city level, a sixth indicator is introduced, which should be presented with the average result obtained for each indicator applied in the hospitals analyzed.

| Percentage obtained | System analysis |
|---|---|
| 0-19% | Unsustainable |
| 20-49% | Problematic |
| 50-69% | Satisfying |
| 70-89% | Fine |
| 90-100% | Excellent |

**Table 4.13:** Evaluation scale for the indicator set.

### Implementation of the HWM indicators in Hospitals

The criteria considered for assessing the HWM system in hospitals were divided into five indicators:

A. collection and SC;

B. storage;

C. local treatment;

D. maintenance and monitoring;

E. awareness, security, and prevention.

Each indicator provides information regarding the topic considered, using qualitative and quantitative data about the management activities applied in the hospitals. For each hospital, the information about its dimension should be presented, in order to compare the data with other sanitary areas: Number of beds; Percentage of beds occupied per year; Number of patients per year; Number of workers; Solid waste produced per year; and HW produced per year.

| Indicator code | N. | Criterion | Description |
|---|---|---|---|
| A. Collection and selective collection | A.1 | Percentage of selective collection | This criterion assesses the amount of HW separated from the MSW. The score is provided in function of the percentage of selective collection known. In particular, the higher range assumed is of 99-100% of selective collection of HW and the absence of infectious waste within the municipal solid waste. |
| | A.2 | Temporary storage | The main factors considered the bags used for the first temporary storage of the HW, as well as the areas dedicated and the quality of the bins. |
| | A.3 | Internal transport | The criterion considers the transport of the HW from the area of generation to the intermediate storage. In particular, the assessment considers the awareness of the staff, the quality of the bags and containers used specifically for the transference. |
| | A.4 | Times of transport to final storage areas | The collection time in internal areas is considered. The service should be applied daily and regulated. The highest score could be achieved by the collection every morning, evening and night. |
| | A.5 | Use of personal protection equipment | The criterion analyze the availability of gloves, suits, goggles, every time that the HW is managed, as well as the sterilization of the containers after transportation. |
| | A.6 | Typologies of waste collected in separate containers | The types of HW selected are important for understanding the quality of the storage and transportation system. The criterion considers the MSW, the sharp waste, infectious, radioactive, pathogens, liquids, chemical and drugs. |

**Table 4.14:** Criteria used to assess indicator A. Collection and selective collection.

Indicator A provides the suggestions for assessing the quality of the collection and SC system of the HW. Table 4.14 reports the description of the six criteria used. The first criterion is quantitative, in order to provide information about the amount of waste selected from the total generated by the hospital. Criteria A.2, A.3, and A.4 refer to the method applied for storing and transporting internally the HW, considering the quality of begs and containers used, for both the temporary storage, the storing time of the HW, the cleanness and the condition of the site. The storage areas can be defined as: first temporary storage, defined as the containers (or bins) for disposing the HW generated at the surgeries; intermediate storage, containers located out of the surgeries, where the HW is gathered and then transported to the final storage site; final storage site, the area for storing the HW collected from the surgeries before its transportation to the final disposal site or treatment plant. The criteria A.2 and A.3 refer to the first temporary and intermediate storage. Criterion A.5 assesses the use of PPE for transporting and storing the HW. Finally, criterion A.6 provides indications about the quality of the SC system of MSW and HW. In particular, differently from indicator A.1, it refers to the types of HW separated at the source.

Table 4.15 summarises the criteria used for assessing the quality of the HW storage (indicator B). The first criterion assesses the awareness of the operators who apply the collection of the HW. Criteria B.2 and B.3 introduced the issue regarding the quality of the area for the intermediate storage of the HW and the time required for transporting the waste to the final storage site. Similarly, with criterion A.5, criterion B.4 evaluates the compliance of the use of PPE of the operators who move the HW to the final storage area. Criterion B.5 assessed the quality of the containers used for the intermediate storage, while B.6 the quality of the final storage site in its totality, therefore in terms of quality of the containers, control of the area and its maintenance.

| Indicator code | N. | Criterion | Description |
|---|---|---|---|
| B. Storage | B.1 | Awareness and consciousness of the staff for the transporting process | The quality of the collection system is assessed in terms of capacity and expertise of the operators, the specialization of the companies involved in the system, the awareness of the personnel, and the monitoring system. |
| | B.2 | Intermediate storage area on-site | The area of the intermediate storage of HW in hospitals is analyzed in function of its maintenance, cleanness, typology and allocation, as well as the limitation of the staff who could enter the area. |
| | B.3 | Storage time in intermediate storage areas | The time required for transporting the HW from intermediate storage to the final storage. The maximum score can be obtained if the HW is removed every 12h, in order to minimize the risk of spread of disease. |
| | B.4 | Personal protection equipment of the staff | Differently between criterion A.5, this criterion assesses the use of personal protection equipment by the staff who transports the HW from the intermediate storage areas to the final one. |
| | B.5 | Container used for the intermediate storage of HW | Differently between the criterion A.2 and B.2, the criterion analyzed the quality of the containers for the intermediate storage. |
| | B.6 | Final storage area and time required before its external transport | The quality of the final area before the transport of HW to the final disposal site or treatment plant is assessed in this criterion. The type of containers used, the cleanness of the area, as well as its cover and monitoring are evaluated. |

**Table 4.15:** Criteria used to assess indicator B. Storage.

Indicator C is assessed against five criteria covering the requirements for an appropriate HW treatment (Table 4.16). The first criterion evaluates the sterilization of the sharps and infectious waste both in large or small scale. Meanwhile, criterion C.4 quantifies the amount of waste treated. The criteria C.2 and C.5 assess the precautions used for treating HW, for reducing environmental impacts, health issues, and the maintenance of the area where the treatment plant is located. Finally, criterion C.3 evaluates the method for wasting the wastewater generated by the hospital, in order to close the loop of the refuses produced at the healthcare center.

Table 4.17 sums up the criteria used for evaluating the quality of the maintenance and monitoring of the HWM system in the hospitals (Indicator D). This indicator set is the one with the highest number of criteria due to its complexity. The first criterion assesses the presence of a manager involved in the monitoring system, as well as of a method for providing an annual report. The second indicator introduces the issue of a periodic assessment regarding the amounts of waste produced per day. Moreover, the criteria D.3 and D.4 evaluate the monitoring of the storage areas and of the service quality. Criterion D.5 specifically assesses the financial sustainability and the counting of the expenses for the HWM system, while criterion D.6 explores the issue related to the control of the health of the staff. Finally, the last criterion evaluates the cooperation of the hospital with external private companies for the monitoring and collection system.

| Indicator code | N. | Criterion | Description |
|---|---|---|---|
| C. Local treatment | C.1 | Treatment of the infectious and sharp HW | The criterion assesses the presence of a treatment plant for the sterilization of the HW. The quality of the treatment is considered for each waste typology, in order to evaluate the availability of the treatment both at large scale or small scale (laboratories or the internal area of surgeries). |
| | C.2 | Precautions applied during the treatment | The criterion considered the precautions used before treatment in an integrated manner, such as the monitoring of the emissions, the quality of the containers used, the trituration before treatment, or generally the pre-treatment, and the operation and maintenance of the plant. |
| | C.3 | Wastewater treatment applied in the hospital | Wastewater treatment is considered for closing the loop of the HW treatment. In particular, the treatment of body fluids, chemicals, the use of the sewage system and the treatment of the sludge. |
| | C.4 | Percentage of HW treated on site | In agreement with criterion A.1, the criterion analyzed the quantity of waste separated treated on-site. Specifically, the percentage of waste treated is assessed, in function of all the HW produced. |
| | C.5 | Treatment area | The quality of the area used for the treatment is considered, in function of quality of the cleanness, the monitoring and the maintenance of the structure used (roof, barriers. . . ) |

**Table 4.16:** Criteria used to assess indicator C. Local treatment.

The last indicator is defined for evaluating the awareness and the prevention implemented by HW operators (Table 4.18). This indicator is composed of five criteria. The first criterion evaluates the presence of internal rules for managing the HW, while criterion E.2 assesses the introduction of information campaigns and training for the staff. Consequently, criterion E.3 introduces the issue about the disclosure of sensitivity materials, which should be provided both to the users of the hospital and to the staff. Likewise, to criterion D.6, the obligation of the vaccines for the staff is also considered within this criterion.

| Indicator code | N. | Criterion | Description |
|---|---|---|---|
| D. Maintenance and monitoring | D.1 | Staff for system monitoring | For the monitoring and management of the HWM system is required a manager, with the implementations of annual reports and constant planning. This criterion assesses the accomplishment of such manager and method. |
| | D.2 | Periodic assessment of the solid waste produced | Monitoring of the selective collection system by the analysis of the quantities produced and material analysis. The analysis should be applied diary in terms of quantities produced, while monthly a report should be drafted. |
| | D.3 | Monitoring of the storage areas and cleaning | This criterion is in agreement with criterion D.1. The quality of the monitoring system should be coordinated by a manager and by entrained staff. The maintenance of the area should be effective, and the cleaning/sterilization is applied daily: such indications should be coordinated and monitored. |
| | D.4 | Assessment of service quality | The assessment considered mainly the opinion of the users of the hospital for analyzing the public opinion. The judgment of the hospital patients should be considered for improving the cleaning applied, while yearly a report about the topic should be drafted. |
| | D.5 | Assessment of expenses and economic sustainability | The financial sustainability should be analyzed in order to improve the system. For that purpose, the expenses should be carefully monitored, data should be reliable and constantly collected, and the administration should be focused on it. Finally, the criterion analyzed the economic sustainability of the whole system for its continuity. |
| | D.6 | Control and monitoring of the injuries of the staff | This criterion is introduced for assessing the monitoring system about the illnesses of the staff and the correlation between disease and sterilization. In particular, it is focused on the monitoring systems of the various pathologies or infections due to HW handling and transportation. |
| | D.7 | Cooperation with external units for assessing the system | Cooperating with public or private companies for the monitoring and maintenance system allows improving the quality of the healthcare facility. Such external companies could be included for the cleaning and the collection systems, as well as the monitoring of the collection and planning. |

**Table 4.17:** Criteria used to assess indicator D. Maintenance and monitoring.

### Implementation of the HWM indicators at municipal level

In parallel with the indicators implemented for assessing the quality of the HWM in hospitals, another indicator is provided, concerning the HWM system at municipal level (Indicator F). Table 4.19 reports the description of the criteria used.

The first criterion evaluates the methodology for treating the HW at municipal level. The second criterion assessed the quality of the transportation while criterion F.3 evaluates the reliability of national and regional regulations about the management of the HW. Criterion F.4 investigates the monitoring system since the presence of an autonomous actor involved in the HW management is compulsory for improving the quality of the system. For assessing financial sustainability, criterion F.5 is introduced, focused on cost accounting. Finally, the last criterion is applied in order to evaluate the collection time of the HW disposed into the final disposal site or treated by the municipal HWM system.

| Indicator code | N. | Criterion | Description |
|---|---|---|---|
| E. Awareness, security and prevention. | E.1 | Internal rule | Internal regulation are assessed in function of its reliability and application. The organization of training and seminars can improve the HWM system and such activities are evaluated within the criterion. |
| | E.2 | Information campaigns and activities for the staff | Correlated with criterion E.1, this criterion considers the application and organization of seminars, meetings for the staff, among other training activities. The main objective is to assess the quality of the information provided and the time used during the year for these activities. |
| | E.3 | Diffusion of informative material about hygiene and good practices for HWM | In agreement with indicator D, this criterion considered the quality of the information provided to the users for accomplishing with the rules of hygiene. The same should be introduced for the staff, in order to constantly inform them about such good practices. The criterion follows the indication of criterion E.2, although it qualify only the use of information materials. |
| | E.4 | Vaccines to local staff | Staff should be vaccinated for reducing the risk of illnesses. These activities should be obligatory, with an appropriate monitoring system. This criterion is similar with criterion D.6, which assesses the monitoring of the injuries and illnesses of the staff. |
| | E.5 | Regulations and methods for preventing injuries | In agreement with criteria D.1, D.5 and B.5, this criterion assess all the activities applied for the prevention. Here the application of rules, the use of good infrastructures and information systems is assessed in an integrated manner. |

**Table 4.18:** Criteria used to assess indicator E. Awareness, security and prevention.

### Assessment of data quality

The last indicator introduced in this study would assess the quality of the information used for implementing the HWM indicators. The quality index should be provided to each criterion of the indicators, in order to evaluate the source of the qualitative and quantitative data reported. Table 4.20 describes the indexes used.

Index A is mainly provided by information collected in continues studies, implemented in more field research, or by official documentation with information available during the years. Such information could be provided by local actors who operate in the hospital or treatment site, or by NGOs that worked in the area for a long time. The index B is the most achievable, since it is associated with the indicators obtained by the information available indirectly or by interviews to local actors, without the support of official documentation. Index C refers to the use of scientific literature or approximation with old documentation or old data. The last index refers to the use of hypothesis, so it is provided in case of lack of data or field inspections.

The average of the quality index obtained for each criterion allows finding an indication about the reliability of the information used for assessing the HWM system. Table 4.21 provides the benchmarks for scaling the quality of the data, introducing an improved index quality, from very low compliance (D) to very high (A). Such indexes should be reported in parallel with the results that will be introduced in the radar scheme, in order to evaluate in a simple way the consistency of the scores obtained.

| Indicator code | N. | Criterion | Description |
|---|---|---|---|
| F. HWM at city level | F.1 | Method of centralized treatment and final disposal | This criterion assesses the method of final disposal or treatment of HW. In particular, it evaluates the engineering of the final disposal site or the treatment technology implemented the environmental monitoring and the type of solid waste introduced. |
| | F.2 | Quality of the transport from hospitals to the treatment plant or final disposal | The quality of the transportation is assessed, in terms of safety precautions, separation of the waste for each topology, sterilization of the containers, and use of appropriate bags. At the same time, the type of truck used for the transportation is also assessed. |
| | F.3 | Local and national laws | This criterion considered the application and the presence of reliable regulations and laws about HWM. The law should speak about collection, treatment and final disposal, analysis of the risk, monitoring and maintenance, cost of the solid waste, economic and environmental sustainability. |
| | F.4 | System monitoring | The analysis is conducted for evaluating the method of the monitoring applied within the study area. In particular, the presence of specific public entities that could qualify the characteristics of the HWM system. |
| | F.5 | Financial sustainability and investment | The percentage of economic resources that covers the expenses is considered within this criterion. Furthermore, the analysis of the investment is carried out, with a particular focus on the cost covered by the income due to HW inflow into the final disposal site. |
| | F.6 | Collection time | This criterion analyzes the daily timescale for the delivery of the HW to the formal waste collection system, as well as the rule for its application. Moreover, the criterion assesses the quality of the monitoring and specifically the method for the application of the selective collection. |
| | F.7 | Personal protection equipment | The quality of the personal protection equipment is assessed, as well as the monitoring of its use and the awareness of the staff involved in the municipal HW treatment or final disposal. |

**Table 4.19:** Criteria used to assess indicator F. HWM at city level.

**Application of the indicators: the case of La Paz, Bolivia**

The indicators were applied in La Paz as example for presenting the potentiality of the methodology in a low-middle income country. As regard HW, the city suffer issues also detected in others low-middle income countries [163]: financial unsustainability, low compliance with storage and collection requirements, difficulties in transportation, treatment and final disposal, lack of awareness about environmental and health risk, and data reliability. The HWM indicators were introduced for assessing and quantifying these issues.

The information required for assessing the HWM system were gathered by field inspections at the sanitary landfill, for assessing current HW final disposal, interviews to the main experts of the local municipal government, private sector and NGOs, and by the assessment of the documentation available at municipal level [164]. Interviews were carried out to the agency responsible of the HW at municipal level, in order to collect information about the HW current management at municipal level. Finally, a

| Value | Quality index | Description |
|---|---|---|
| 3 | A | The qualitative information are collected from field studies or site visits replicated in different periods of the year and with various analysis, or with specification about the time in which the indicators are applied. The qualitative data collection can be also supported by official documents (national or international) that provides information of the period of analysis and the methods used for assessing it (the indirect information derived from field studies too). The quantitative information are of yearly studies, collected with methods well explained, replicable and referred to the period of analysis. This index is usually provided for studies implemented directly in the field and for at least one year of analysis, in order to evaluate the seasonality and the fluctuation of waste generation or of the monitoring. |
| 2 | B | The quantitative and qualitative information are collected by direct studies (interviews, site visits, field inspections) but in a limited period (few days or weeks). The data collection can be supported by indirect documentation (it is not provided directly buy the hospital) implemented by experts in the field, although it is not official and reviewed by international or national agencies. In case of quantitative data, they can be obtained by direct interviews to local actors, although without the support of documentation. |
| 1 | C | Qualitative and quantitative data are always collected by indirect studies (review of documents and scientific articles). Data are collected also from formal or informal documents where the methods are not well reported or where the data are older than the assessment implemented (more than two years old). The index refers also to documents supported by international and national agencies, but with data older than the period of implementation of the indicators. |
| 0 | D | There is no documentation for supporting the indicator or the criteria, neither field inspections, visits nor interviews. The information is provided by hypothesis. |

**Table 4.20:** Indicator for assessing the data quality.

| Very low | Low | | Medium-low | | Medium-high | | High | | Very high |
|---|---|---|---|---|---|---|---|---|---|
| 0-0.2<br>D | 0.21-0.5<br>D+ | 0.51-0.9<br>C- | 0.91-1.1<br>C | 1.11-1.5<br>C+ | 1.51-1.9<br>B- | 1.91-2.1<br>B | 2.11-2.5<br>B+ | 2.51-2.9<br>A- | 2.91-3<br>A |

**Table 4.21:** Indicator for assessing the data quality.

field study campaign was carried out in three hospitals of the city, in order to assess qualitatively the generation, collection, storage, transportation and treatment of HW. The three hospitals analyzed, were considered the most representative of the HWM system of the city, due to its dimension, amounts of clinical area, and waste generation. Information about the HWM in these hospitals and about the HWM system at municipal level are provided in the Results section.

The data gathered were used for completing the indicators. The field inspection at the hospitals and the interviews to the local stakeholders were implemented from December 2018 to April 2019. Previous data were gathered from a study introduced by the NGOs Swisscontact in 2003 [164].

### 4.5.3 Results

#### HWM system of the hospitals

La Paz has about 20 hospitals with a production of HW in 2003 ranging from 2 kg to $64\,kg\,day^{-1}$ per hospital. The number of bed varied from 22 to about 470, for an averaging production rate of $0.5\,kg\,bed^{-1}day^{-1}$ [164]. These data suffer from errors due to the non-compliance of the HW SC in the majority of the hospitals, where the waste was mixed with the MSW, and due to the period of analysis, implemented for eight days in 2003. Such data are completed with the data gathered during the fieldwork in 2019.

The quantity of waste produced in 2003 and in 2018 did not change considerably since, at municipal level, the production of HW passed from about $1\,t\,d^{-1}$ to about $1.5\,t\,d^{-1}$. To date, the HW is delivered to the municipality in red bags and stored in separate containers before its collection and transportation. In-site HW treatment is not applied although, in a few hospitals, the treatment of sharps is implemented by autoclave systems. A few pilot projects were implemented, with poor results. The wastewater is always sent to the sewage system, although no treatment is implemented at municipal level, increasing the contamination of water bodies.

The quantities of waste and the dimension of the hospitals choose for implementing the indicators are reported in table 4.22, comparing the data obtained from technical documentation [164] and the ones acquired by the interviews and field study carried out in 2019. Hospital 1 generates about $13 - 68\,t$ of HW per year, with the minimum HW production rate per bed lower than the average city generation estimated in 2003 (about $0.5\,kg\,bed^{-1}d^{-1}$). Hospital 2, with about $25 - 29\,t$ of HW generated per year and 110 beds available, can be considered smaller than Hospital 1, although with a higher daily generation per bed. In 2018, Hospital 3 has no data about the HW generation and this represents a first management limit. Moreover, data about the number of workers and patients per day are not available, or they are not uniform in terms of definitions; therefore, they are not reported in table 4.22. A brief description of the three hospitals, according to the site visits and interviews, is introduced below, following the structure of the indicator set.

| | | n. of beds | n. of beds occupied per day [%] | MSW produced [$kg\,d^{-1}$] | HW produced [$kg\,d^{-1}$] | HW per bed [$kg\,bed^{-1}d^{-1}$] |
|---|---|---|---|---|---|---|
| 2003 | Hospital 1 | 338 | 99 | 290 | 65 | 0.19 |
| | Hospital 2 | 95 | 60 | 54 | 53 | 0.56 |
| | Hospital 3 | 422 | 87 | 470 | 42 | 0.1 |
| 2018 | Hospital 1 | 366 | 120 | 179-248 | 35-187 | 0.1-0.51 |
| | Hospital 2 | 110 | 71 | 54-70 | 69-80 | 0.63-0.73 |
| | Hospital 3 | 436 | 115 | N.A. | N.A. | N.A. |

**Table 4.22:** Quantitative data about three public hospitals of La Paz, comparing 2003 (Swisscontact, 2003) with 2018 (field study).

#### Hospital 1

**(A)**. The HW SC can be qualitatively evaluated between 75-98%, where sharps, medicines, and infectious waste are separated from the MSW. The first storage areas are located in the bathrooms of the patients or in the surgery areas. These areas are monitored and clean, but the HW is in contact with the users of the hospital. The waste is stored here for 12 or 24h, increasing the exposure risk. The operators who move the HW are also in charge of moving the patients and distributing the meals. Again, the risk of exposure is very high also because de PPE is basic (gloves, mask and overall), and it is not daily changed.

**(B)**. The HW is transported from the intermediate storage area to the final one by operators of a private company. The operators are not always trained and informed. Moreover, they are not always supported by a health monitoring system, while vaccines are not obligatory. The intermediate storage area is located outside the clinics, in contact with the users of the hospital and sometimes out of coverage. The bins used are most of the time open, the color is not equal for all the HW containers, and are not always separated from MSW, increasing the risk of mixing and contamination. The HW is collected every 24h, and the storing time is variable in function of the delivery time of each clinic. At the final storage area, the HW is not always disposed of in containers. The bags are most of the time left outside, in contact with the ground and the MSW.

**(C)**. At the hospital, a HW pre-treatment plant is available. However, it is not working and the waste is not sterilized after treatment: any external monitoring system is implemented. Therefore, the waste is stored and delivered to the municipal HW collection system. Small sharps are treated with chlorinated compounds, and the laboratory waste is treated by small autoclaving systems. It can be estimated that less than 5% of the waste is currently pre-treated.

**(D)**. The HWM system is not daily monitored, there is not a reporting system and the analysis of the fraction of HW generated or disposed of with the MSW are not carried out. Therefore, it is not excluded the possibility that the HW can be mixed with the MSW. The daily generation rate of waste is neither monitored, although every three months the quantities of waste generated in one week are measured and reported for estimating the number of bags required for the collection system. The economic expenses are known only in terms of bags required for the system, but there is no awareness about the HWM fee paid or required for the functioning of the system. Finally, the opinion of the users of the hospital is not considered, although pilot programs for its assessment are in place.

**(E)**. One or two times per year, the healthcare operators are trained in specific seminars, although they are not obligatory. There is a specific manual for the management of HW, although not all the operators are aware about its accessibility. There are not meetings for coordinating and monitoring the system, neither information materials nor campaigns related to HW. The health monitoring system for the operators is not organized or obligatory; there is not a standard emergency system in case of injuries or cuts from HW. The PPE is not suited for transportation of the HW from the intermediate to the final storage area. The operators are most of the time young and unaware of the risk that they are exposed.

**Hospital 2**

**(A)**. The SC is implemented at the hospital, with about 75-98% of selection rate. The 100% is not always obtained due to possible errors and lack of awareness of the healthcare operators about the methods for collecting the HW. The first storage areas are located in infirmary, in the bathrooms or patients' room. The HW is collected three times per day, with a private company in charge of the collection. The operators are dedicated to the HW collection. They are trained and informed from the nurses, although they did not participate to seminars or specific courses.

**(B)**. The operators are not trained by the private agency, they are not obligated to be vaccinated or monitored. The intermediate storage areas is located in specific rooms, clean and well reported. Here, the HW is daily collected three times, with specific hours and schedules. The bins are well reported and the colour is equal for all. The final storage area is located outside the structure, in a specific room, well reported and monitored, far from the users and with access only to the operators.

**(C)**. The HW pre-treatment is implemented only for a small fraction of waste, mainly from the laboratories. Some sharp waste are treated with chlorinated compounds and delivered in bottles or small plastic containers. The liquid HW are delivered to the sewage system, while the chemical compounds used at the laboratories is stored in plastic bottles and delivered with the infectious waste. The solid waste treated can be considered less than 5% of the total generated in the structure.

**(D)**. The private company in charge for managing the HW provide a monthly report to the director of the hospital, with analysis about the main difficulties found. Every year, a report about the generation of HW is drafted, providing data about the HW generation and the typology of waste generated. The private company continue the monitoring of the areas by daily assessment. The users can provide advises for improving the system, although there is not an organization for its collection and assessment. The financial expenses are not known due to the lack of data, only available to the private company; therefore, the hospital pays for the private service, but is not aware about how the system could be improved. Every year the epidemiological director ask to the operators and the staff the report about their health condition, monitoring the presence of pathologies correlated with their work.

**(E)**. The HWM is regulated by internal norms and documentation in agreement with the national laws of biosafety. There are not meeting for monitoring the system, neither courses or seminars for the operators. There is not a specific area for the health monitoring of the operator internal of the hospital, while some operators are not aware about the requirement to be vaccinated or have not a medical insurance. However, there are specific guidelines that should be respected in case of injuries or cuts.

#### Hospital 3

**(A)**. The SC is estimated to be 75-98% like the previous hospitals. Therefore, the SC system is always implemented. However, the MSW containers often are contaminated with HW and vice versa, both in intermediate and final storage areas. The HW operators are in charge of the collection of the waste. Moreover, they should deliver the meals to the patients, improving the risk exposure to disease and pathologies. The HW bins are located in the offices, bathrooms and surgeries areas, in areas also dedicated to the patients. The HW is collected two times per day and directly stored in the final storage area, without intermediate storing, increasing the risk of contamination.

**(B)**. The HW operators are not trained or informed about the risk of managing infectious waste. There is not a healthcare system in place for the operators, vaccines are not obligatory. The PPE is composed of gloves and masks, changed one or two times per week. The final storage area is located in a closed room outside the hospital, cleaned every day by the HW operators. However, sometimes the HW is mixed with MSW, increasing the risk of contamination and infections.

**(C)**. HW is pretreated only at the laboratories, with a treatment rate of less than 5%. The laboratory waste is treated by autoclave and wasted with the MSW or HW.

Liquid waste is mostly delivered with infectious waste or released into the sewage system.

**(D)**. To date, the HWM system is not monitored. In 2019 was created the epidemiology department for monitoring the HW generation, collection, and final disposal. Therefore, no previous data about HW generation are available. There is not a monitoring system for assessing the organization and cleanness of the storage area or of the methods for collecting waste. The economic expenses are not known; the main costs known regards the bags used for the collection system. Therefore, there are no internal policies for reducing HW generation or for improving the HWM system in terms of investments and infrastructures.

**(E)**. The HWM system is organized in function of an internal plan for reducing health risks. However, the internal personnel is not aware of its availability. There are not internal meeting or seminars regarding HWM. The diffusion of information material is not implemented, neither campaigns nor sensitivity activities for increasing the operators' awareness. The health visits are not organized by the hospital and are not obligatory; therefore, the monitoring system of operators' health is not in place. The main issue regards the management of sharps waste since the PPE is not suited for its management.

### Implementation of the indicators

The introduction of the indicator set allows comparing the hospitals in a simple scheme. The results of the scores obtained for the three hospitals of La Paz, in agreement with the description of the previous section, are reported in Figure 4.32. The figures depict the situation of the three hospitals in function of the compliance with the criteria introduced. Moreover, in table 4.23 the quality of the data collected is reported for each indicator and for each hospital. The average quality of the data used for implementing the indicators can be considered medium-high for hospital 3, where the availability of data is lower than the other hospitals, and high for hospital 1 and 2, where data are most of the time available together with appropriate documentation.

It is clearly visible how indicators regarding the quality of treatment are the ones that obtained the lowest score for the three case studies. This is made more negative considering the lack of treatment at municipal level. However, collection and storage are of good compliance for both hospital 1 and hospital 2, since the SC is implemented with appropriate begs and containers. The worst situation has been found in hospital 3, particularly regarding the storage system, maintenance and monitoring.

| Indicators | Hospital 1 | | Hospital 2 | | Hospital 3 | |
|---|---|---|---|---|---|---|
| | Average | Index | Average | Index | Average | Index |
| A | 2 | B | 2 | B | 2 | B |
| B | 2.17 | B+ | 2 | B | 2 | B |
| C | 2.2 | B+ | 1.6 | B- | 1.6 | B- |
| D | 2.57 | A- | 2.57 | A- | 2.43 | B+ |
| E | 2 | B | 2.2 | B+ | 2 | B |
| Average | 2.23 | B+ | 2.13 | B+ | 2.08 | B |

**Table 4.23:** Quantitative data about three public hospitals of La Paz, comparing 2003 (Swisscontact, 2003) with 2018 (field study).

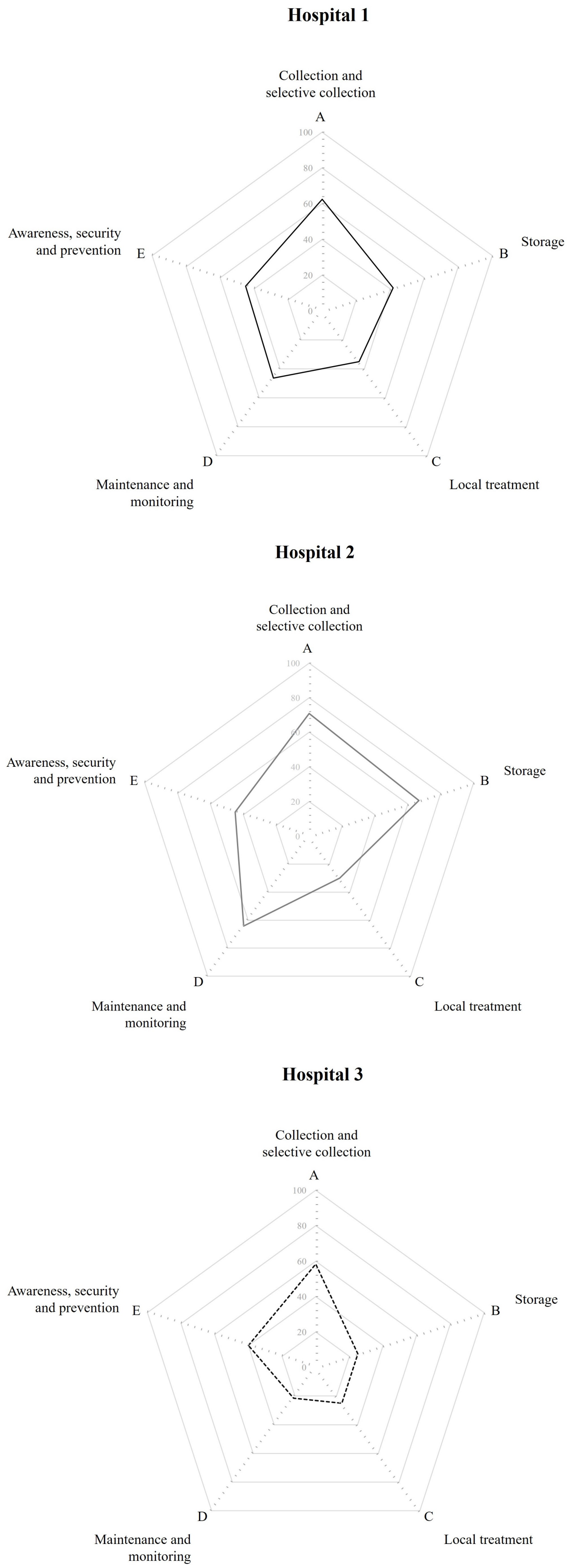


**Figure 4.32:** HWM system assessed in three hospitals of La Paz: Hospital 1, Hospital 2, Hospital 3.

### HWM system at Municipal level

At municipal level, the HW is collected diary by a private company and disposed of to the sanitary landfill, where the waste is stored of in separate cells. The collection trucks are specific for the collection of HW, with the refrigeration system. The operators are trained for managing infectious waste, although the main risk is due to the possible mix of MSW streams with HW. The final disposal and transportation comply with the local national regulations, introduced for the first time in 2008. The cost of the HWM system is totally in charge of the municipality, without the involvement of the hospitals for the payment of the transportation and final disposal. The system is monitored by an autonomous municipal agency and by the national Ministry of health.

According to the score obtained by indicator F, the HWM system applied in La Paz can be considered ‘satisfying’ since the HW are managed with precaution, trying to avoid the mixing with the MSW, there are specific laws and regulations and a controlled final disposal site. Moreover, the HW collection and final disposal are implemented in cooperation with the private sector, which allows the implementation of controlled transportation of the HW. The main weak point is the financial sustainability of the system, due to the lack of revenues collected from the hospitals.

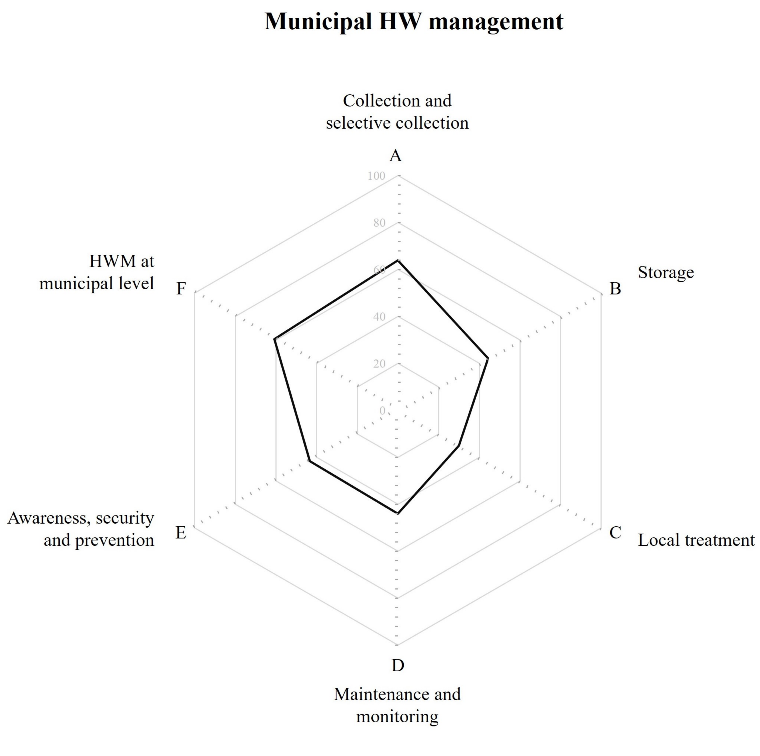


**Figure 4.33:** HWM system assessed at municipal level.

For depicting the HWM system at municipal level, the average results obtained for the three hospitals in parallel with indicator F are represented in Figure 4.33. Collection and sorting received a good score, while financial sustainability, final disposal, and prevention could not be considered satisfying. Therefore, results suggest that the main issues regarding HWM are the implementation of HW local treatment systems, followed by awareness, security and prevention, and maintenance and monitoring. Local treatment obtained a score below 30%, which allows considering the system as ‘problematic'. The same consideration can be introduced for indicators B, D and E, with the only exception for indicator A, which can be considered 'satisfying'. For this reason, raise the need to apply new management projects about the introduction of new infrastructures, information campaigns, and technical support, in order to improve local sustainability, in agreement with the objectives of the sustainable development goals.

### 4.5.4 HWM issues in La Paz and other developing cities

La Paz suffers HWM due to its low financial sustainability. However, it could be considered a good example as regard first collection (at the source), transportation and final disposal compared with other developing cities [137, 165]. The lack of treatment plants, on-site and off-site, are the main barriers for implementing a sustainable system, in parallel with the lack of information campaigns at hospital and municipal level. Moreover, the monitoring process should be improved, both at the hospital and at municipal level, in order to evaluate the main actions required for improving the current HWM situation.

The objective of an appropriate HWM system in La Paz should regard the reduction of environmental impacts, the improvement of the life quality of the population and the progress with the management of the final disposal site. The implementation of information campaigns, together with the introduction of appropriate infrastructures (bins, storage areas, collection trucks) can be associated to the implementation of appropriate treatment plants, in order to spread the sustainability of SWM at municipal level. Therefore, international economic resources must be found in order to start pilot projects and support the implementation of new management approaches for improving collection, transportation and treatment systems.

In developing countries, effective planning of HWM is difficult due to various factors, such as lack of political awareness among environmental and health issues, financial sustainability and technological facilities [166]. Moreover, the lack of proper tools and methodologies for planning new management plans is also a barrier [167]. The main objective that should be achieved by low-income countries is the proper separation of infectious and municipal wastes at the source, which is an essential step towards mitigating environmental and health risks and minimizing the cost of the HWM [168]. However, the waste separation rate suffers from the insufficient application of the operating procedure, which should be introduced for reducing the costs [169].

In Cameroon, HW is disposed of in open dumps mixed with MSW or disposed of in incinerators often poorly designed, due to the lack of an integrated approach to policymaking [170]. In Iran, the lack of separation of HW, specific regulations, proper waste treatment, and disposal along with MSW, were the main issues detected for introducing a sustainable HWM system [171]. In Ghana, many hospitals do not have any separate collection or disposal program for pharmaceutical waste and more than half of the population disposed of pharmaceutical waste through the MSW that end up in the landfills or dump sites [172]. However, it has been proved that the SC of HW allows decreasing the expenses for its management in hospitals [173], so it should be considered in order to improve environmental, social and economic sustainability.

The application of recycling of sterilized plastic and metal parts, mechanical needle removers, safe transport and storage, appropriate treatment, documentation, training, and equipment maintenance can improve the quality of HWM systems, reducing environmental and health risks [147]. Many treatment technologies could be considered for reducing HW impacts. Steam autoclave is the most used to sterilize bacteria in order to determine an alternative to incineration technologies [174]. However, other appropriate technologies can be considered [157].

### 4.5.5 Potentiality of the HWM indicators

The HW indicators introduced in this article allowed comparing the HWM system among three hospitals of La Paz, providing a preliminary assessment of the HWM system at municipal level. Moreover, thanks to the comparison with the data quality, the indicators can be assessed about their reliability. The approach can be useful for providing suggestions to the local stakeholders and policy-makers about the improvements required for obtaining the highest score and for taking into account management issues that were not considered.

The indicators can be used for comparing hospitals in the same city, cities in the same country and cities among different continents, providing a benchmark related to the income level, environmental characteristics and social behavior. Therefore, the indicator set can be a tool for contributing to the improvement of the awareness about HWM issues and management requirements for boosting sustainability and health at global level.

Therefore, the next step is the implementation of the method in other case studies, in order to compare other realities in terms of quality of the HWM system. It can provide indications about which solution should be prioritized about collection, treatment and final disposal, spreading the awareness about health risks and introducing new options regarding prevention and monitoring systems. The indicators do not suggest the most appropriate technology for the treatment of HW, as introduced by other methods [175], but assess its implementation and the precautions implemented, suggesting that the most appropriate practice is the HW sterilization at the source, as recommended by the WHO.

### 4.5.6 Limits of the study and future improvements

The research conducted in La Paz was implemented only within one-fourth of the hospitals of the city, providing a partial indication of the municipal HWM system. Therefore, future improvements regard the application of the indicators in other hospitals as well as small clinics and healthcare facilities. Moreover, the indicators were implemented only in La Paz, while more case studies should be introduced at national level for assessing the main differences and the applicability of the indicators in Bolivia.

The approach was not replicated in other countries. The research should be repeated in other countries with different regulations and social behavior, in order to assess the reliability of the indicators also for other case studies. Moreover, for the same reason, the indicators cannot be defined as definitively implemented, since the method for providing the scores could vary in function of various factors specific to a case study. Therefore, the indicator set should be considered under development and it should be developed in other future researches.

The last limit of the study is its implementation in a limited period. The indicators should be introduced during the years, in order to assess possible improvements carried out after pilot project or sensitivity campaigns. Future researches should be focused on the implementation of the same indicators within the same hospitals analyzed, in order to provide a dynamic view of the HWM system implemented at hospital and municipal level.

### 4.5.7 Remarks and considerations

The study presented can be considered the first step for the application of a new management tool for planning HWM systems in developing countries, in agreement with the indications provided by the WHO. Studies related to the background of HWM systems are of utmost importance for assessing the best future scenarios. The indicators suggested can be considered a reliable tool for assessing the current HWM system in low-middle income countries, since the availability of a list of management requirements, as well as a method for classifying the main weak points of a city or hospital, can be useful for planning appropriate collection, transportation, and treatment systems.

The application of HWM indicators should be considered in order to spread the awareness of the stakeholders involved in the HWM systems. At the same time, integrated indicators should be used at international level for comparing globally the main challenges in HWM, specifically in the developing world, for planning specific actions. The objective is to assess the main weak points of each study area in function of its environmental, social and economic system, for learning how the typical barriers of a low-income economy can be overcome. The method proposed can be considered another contribution that moves to this direction. This research is useful as starting point for introducing the methodology provided, which could be applied in other developing cities worldwide. The proposed indicator can be used as a decision support tool for the analysis of a HWM system by governments, authorities, and hospitals, following the indications provided by the WHO. Moreover, this work is a contribution as regards the investigation of HWM in La Paz, and the introduction of management tools useful for understanding current storage, collection, treatment and final disposal practices in this context.

HWM in La Paz represents an issue that should be investigated, in particular as regards appropriate treatment technologies. Regulation systems and SC methodologies are still under development, although the final disposal to the sanitary landfill cannot be the most appropriate management practice for supporting sustainability. Future application of the method can be related to other waste streams, such as WEEE, used tires or C&DW, covering the requirement of appropriate management tools for assessing international waste management issues. The main objective is to support the implementation of sustainable development and the CE at global level, with attention to the developing world.

## 4.6 Discussion

This chapter reported five researches and methods for analyzing the SWM system of La Paz with different approaches. The implementation of theoretical and practical studies allow deepening the SWM issues and opportunities in the city, considering environmental, social and economic aspects.

The social survey at municipal level should be considered the first step for understanding the current management practice perceived by the citizens, evaluating the population behavioiur regarding MSW SC. The study demonstrated how the inclusion of the informal sector is just supported by the citizens and should be only reinforced with municipal campaigns and specific regulations. Moreover, the survey reported that the informal sector can be considered an alley for improving the RR of the city and La Paz can be considered as a good example for implementing recycling policies in low-middle income contexts

As second step, the LCA allows introducing an environmental assessment of future MSWM scenarios. The academic licensing (free of charge) of an LCA software can be potential for improving awareness and methodological knowledge. The analysis suggested to implemented SC systems, in order to reduce environmental impacts, while the activity of the informal sector is the first step for implementing a CE system at municipal level.

The third analysis included economic assessments, supported by the use of GIS. The use of GIS allows demonstrating the main advantages of the inclusion of the informal sector in terms of reduction of MSW collection routes, SSC, and investment costs. Moreover, informal activities allow increasing the recycling rate, boosting the circular economy principles. Such issue should be highlighted to local stakeholders, in order to enhance the awareness of authorities in implementing integrated assessment in GIS environments, considering the activity of the informal sector.

Fourth, the implementation of a small scale SC system demonstrated the main issues detectable in these contexts, such as the lack of awareness, financial and political support. The good results of the project were obtained also thanks to the habit of the students to implement the SC of recyclable waste at home (mainly delivered to the informal sector). The positive results obtained suggest replicating the system in other areas of the city in order to improve the recycling chain of a region, supporting the local economy and reducing environmental impacts, especially due to the uncontrolled final disposal. The introduction of such SC systems can produce positive effects both at University and municipal level, supporting the activity of the informal or formal recycling sector

Finally, the application of SWM indicators should be considered in order to spread the awareness of the stakeholders involved in the SWM systems. In particular, the SWM indicators were implemented for assessing the HWM system of La Paz, with the objective of analyzing the main weak points and for learning how the typical barriers of a low-income economy can be overcome. The proposed indicator can be used as a decision support tool for the analysis of a HWM system by the local government, authorities, and hospitals, following the indications provided by the WHO.

On balance, the implementation of the analysis presented in this Chapter demonstrated that the informal sector allows:

1. Improving population awareness about recycling and SC schemes;

2. Reducing global environmental impacts due to recycling;

3. Reducing economic expenses if compared with a complete SC system;

4. Supporting the introduction of SC activities thanks to the capacity of the citizens developed due to their activities.

Moreover, the results of the researches conducted allows providing important evidences about the application of methodological approaches for supporting the implementation of SWM programs. In particular:

- Social surveys are imperative for evaluating current MSWM system with the view of the most important users: the citizens.

- LCA can provide first considerations for evaluating the environmental impacts due to the whole MSWM system.

- Analysis with GIS can provide insights about the economic and managerial feasibility of the implementation of SC systems.

- SC systems at pilot scale are compulsory for understanding main issues in context where circular economy activities should start from zero.

- SWM indicators are required in order to assess the current management system with reliable methods.

Therefore, these items should be used and considered for supporting the implementation and planning of effective MSWM systems. In particular, these actions can be used for supporting the submission of MSWM projects to international founders, in order to motivate and reinforce the activities foreseen within the proposals in low income regions.

The next chapter provides evidences of the application of some of these items in projects submitted to international founders and for starting international cooperation projects.

# Bibliography

[1] Ferronato N , Ragazzi M., Torrez Elias M.T., Gorritty Portillo M.A., Guisbert Lizarazu E.G. and Torretta V., 2019. Application of healthcare waste indicators for assessing infectious waste management in Bolivia. Waste Management & Research, 1-15.

[2] Sidique, S.F., Lupi, F., Joshi, S. V., 2010. The effects of behavior and attitudes on drop-off recycling activities. Resour. Conserv. Recycl. 54, 163–170.

[3] Dai, X., Han, Y., Zhang, X., Hu, W., Huang, L., Duan, W., Li, S., Liu, X., Wang, Q., 2017. Comparison between students and residents on determinants of willingness to separate waste and waste separation behaviour in Zhengzhou, China. Waste Manag. Res. 35, 949–957.

[4] González-Torre, P.L., Adenso-Díaz, B., 2005. Influence of distance on the motivation and frequency of household recycling. Waste Manag.

[5] De Feo, G., Williams, I.D., 2013. Siting landfills and incinerators in areas of historic unpopularity: Surveying the views of the next generation. Waste Manag. 33, 2798–2810.

[6] Song, Q., Wang, Z., Li, J., 2012. Residents' behaviors, attitudes, and willingness to pay for recycling e-waste in Macau. J. Environ. Manage. 106, 8–16.

[7] Afroz, R., Hanaki, K., Tuddin, R., Ayup, K., 2010. A survey of recycling behaviour in households in Dhaka, Bangladesh. Waste Manag. Res.

[8] Janmaimool, P., 2017. Application of protection motivation theory to investigate sustainable waste management behaviors. Sustain.

[9] Wang, F., Cheng, Z., Reisner, A., Liu, Y., 2018. Compliance with household solid waste management in rural villages in developing countries. J. Clean. Prod.

[10] Abbondanza, M.N.M., Souza, R.G., 2019. Estimating the generation of household e-waste in municipalities using primary data from surveys: A case study of Sao Jose dos Campos, Brazil. Waste Manag.

[11] Cobbinah, P.B., Addaney, M., Agyeman, K.O., 2017. Locating the role of urbanites in solid waste management in Ghana. Environ. Dev. 24, 9–21.

[12] Babaei, A.A., Alavi, N., Goudarzi, G., Teymouri, P., Ahmadi, K., Rafiee, M., 2015. Household recycling knowledge, attitudes and practices towards solid waste management. Resour. Conserv. Recycl. 102, 94–100.

[13] Sukholthaman, P., Chanvarasuth, P., Sharp, A., 2017. Analysis of waste generation variables and people's attitudes towards waste management system: a case of Bangkok, Thailand. J. Mater. Cycles Waste Manag. 19, 645–656.

[14] Pansuk, J., Junpen, A., Garivait, S., 2018. Assessment of air pollution from household solid waste open burning in Thailand. Sustain.

[15] Ferronato, N., Gorritty Portillo, M.A., Guisbert Lizarazu, E.G., Torretta, V., Bezzi, M., Ragazzi, M., 2018. The municipal solid waste management of La Paz (Bolivia): Challenges and opportunities for a sustainable development. Waste Manag. Res. 36.

[16] Mukherji, S.B., Sekiyama, M., Mino, T., Chaturvedi, B., 2016. Resident knowledge and willingness to engage in waste management in Delhi, India. Sustain. 8.

[17] Vaccari, M., Torretta, V., Collivignarelli, C., 2012. Effect of improving environmental sustainability in developing countries by upgrading solid waste management techniques: A case study. Sustainability 4, 2852–2861.

[18] Creative Research Systems (CRS), 2010. Sample Size Formulas for Our Sample Size Calculator. Available at: http://www.surveysystem.com/sample-size-formula. htm. Last accessed February 2019.

[19] Ferronato, N., D'Avino, C., Ragazzi, M., Torretta, V., De Feo, G., 2017. Social surveys about solid waste management within higher education institutes: A comparison. Sustain. 9.

[20] Loan, L.T.T., Nomura, H., Takahashi, Y., Yabe, M., 2017. Psychological driving forces behind households' behaviors toward municipal organic waste separation at source in Vietnam: a structural equation modeling approach. J. Mater. Cycles Waste Manag.

[21] Pakpour, A.H., Zeidi, I.M., Emamjomeh, M.M., Asefzadeh, S., Pearson, H., 2014. Household waste behaviours among a community sample in Iran: An application of the theory of planned behaviour. Waste Manag.

[22] Stoeva, K., Alriksson, S., 2017. Influence of recycling programmes on waste separation behaviour. Waste Manag.

[23] Seacat, J.D., Northrup, D., 2010. An information-motivation-behavioral skills assessment of curbside recycling behavior. J. Environ. Psychol. 30, 393–401.

[24] Rojas C., A., Yabar, H., Mizunoya, T., Higano, Y., 2018. The Potential Benefits of Introducing Informal Recyclers and Organic Waste Recovery to a Current Waste Management System: The Case Study of Santiago de Chile. Resources.

[25] Silva de Souza Lima, N., Mancini, S.D., 2017. Integration of informal recycling sector in Brazil and the case of Sorocaba City. Waste Manag. Res.

[26] Hartmann, C., 2018. Waste picker livelihoods and inclusive neoliberal municipal solid waste management policies: The case of the La Chureca garbage dump site in Managua, Nicaragua. Waste Manag.

[27] Paredes F.M. (2008). Estudio de caracterización de residuos sólidos reciclables en el área urbana del municipio de La Paz, informe final. Gobierno Municipal de La Paz, Sistema de regulación y supervisión municipal (SIREMU).

[28] Rutkowski, J., Rutkowski, E., 2017. Recycling in Brasil: Paper and Plastic Supply Chain. Resources.

[29] Ghesla, P.L., Gomes, L.P., Caetano, M.O., Miranda, L.A.S., Dai-Prá, L.B., 2018. Municipal solid waste management from the experience of São Leopoldo/Brazil and Zurich/Switzerland. Sustain.

[30] Alzate-Arias, S., Jaramillo-Duque, Á., Villada, F., Restrepo-Cuestas, B., 2018. Assessment of government incentives for energy fromwaste in Colombia. Sustain.

[31] Laurent A, Clavreul J, Bernstad A, Bakas I, Niero M, Gentil E, ... and Hauschild MZ (2014) Review of LCA studies of solid waste management systems–Part II: Methodological guidance for a better practice. Waste management 34(3): 589-606.

[32] Giugliano, M., Cernuschi, S., Grosso, M., & Rigamonti, L. (2011). Material and energy recovery in integrated waste management systems. An evaluation based on life cycle assessment. Waste Management, 31(9-10), 2092-2101.

[33] Khoo HH (2009) Life cycle impact assessment of various waste conversion technologies. Waste management, 29(6): 1892-1900.

[34] Khandelwal H, Dhar H, Thalla AK and Kumar S (2018) Application of life cycle assessment in municipal solid waste management: A worldwide critical review. Journal of cleaner production 209: 630-654.

[35] Gentil EC, Damgaard A, Hauschild M, Finnveden G, Eriksson O, Thorneloe S, ... and Ii R (2010) Models for waste life cycle assessment: review of technical assumptions. Waste Management 30(12): 2636-2648.

[36] ISO (2006) ISO 14040 international standard. In: Environmental Management – Life Cycle Assessment – Principles and Framework. International Organisation for Standardization, Geneva, Switzerland.

[37] Fiorentino G, Ripa M, Protano G, Hornsby C and Ulgiati S (2015). Life cycle assessment of mixed municipal solid waste: multi-input versus multi-output perspective. Waste management 46: 599-611.

[38] Zhao W, Van Der Voet E, Zhang Y and Huppes G (2009) Life cycle assessment of municipal solid waste management with regard to greenhouse gas emissions: case study of Tianjin, China. Science of the total environment 407(5): 1517-1526.

[39] Rajcoomar A and Ramjeawon T (2017) Life cycle assessment of municipal solid waste management scenarios on the small island of Mauritius. Waste Management & Research 35(3): 313-324.

[40] Rana R, Ganguly R and Gupta AK (2019) Life-cycle assessment of municipal solid-waste management strategies in Tricity region of India. Journal of Material Cycles and Waste Management 21(3): 606-623.

[41] Zhou Z, Tang Y, Dong J, Chi Y, Ni M, Li N and Zhang Y (2018). Environmental performance evolution of municipal solid waste management by life cycle assessment in Hangzhou, China. Journal of environmental management, 227, 23-33.

[42] Yay ASE (2015) Application of life cycle assessment (LCA) for municipal solid waste management: a case study of Sakarya. Journal of Cleaner Production 94: 284-293.

[43] Sharma BK and Chandel MK (2017) Life cycle assessment of potential municipal solid waste management strategies for Mumbai, India. Waste Management & Research 35(1): 79-91.

[44] Cleary J (2009) Life cycle assessments of municipal solid waste management systems: A comparative analysis of selected peer-reviewed literature. Environment international 35(8): 1256-1266.

[45] Di Maria F and Micale C (2014) A holistic life cycle analysis of waste management scenarios at increasing source segregation intensity: The case of an Italian urban area. Waste management 34(11): 2382-2392.

[46] Bovea MD, Ibáñez-Forés V, Gallardo A and Colomer-Mendoza FJ (2010) Environmental assessment of alternative municipal solid waste management strategies. A Spanish case study. Waste Management 30(11): 2383-2395.

[47] Fiksel J and Lal R (2018) Transforming waste into resources for the Indian economy. Environmental Development: 26, 123-128.

[48] Toshiki K, Giang PQ, Serrona KRB, Sekikawa T, Yu JS, Choijil B and Kunikane S (2015) Effects of introducing energy recovery processes to the municipal solid waste management system in Ulaanbaatar, Mongolia. Journal of Environmental Sciences 28: 178-186.

[49] Finkbeiner M, Schau EM, Lehmann A and Traverso M (2010) Towards life cycle sustainability assessment. Sustainability 2(10): 3309-3322.

[50] Schiavon M, Ragazzi M, Rada EC and Merler G (2014) Proposal for the correct management of the life cycle assessment results from integrated municipal solid waste treatment. WIT Trans. Ecol. Environ 180: 163-173.

[51] Scheinberg, A.; Spies, S.; Simpson, M.H.; Mol, A.P.J. Assessing urban recycling in low- and middle-income countries: Building on modernised mixtures. Habitat Int. 2011, 35(2), 188–198.

[52] Ferronato, N.; Rada, E.C.; Gorritty Portillo, M.A.; Cioca, L.I.; Ragazzi, M.; Torretta, V. Introduction of the circular economy within developing regions: A comparative analysis of advantages and opportunities for waste valorization. J. Environ. Manage. 2019, 230, 366–378.

[53] Steuer, B.; Ramusch, R.; Part, F.; Salhofer, S. Analysis of the value chain and network structure of informal waste recycling in Beijing, China. Resour. Conserv. Recy. 2017, 117, 137–150.

[54] Botello-Álvarez , J.E.; Rivas-García, P.; Fausto-Castro, L.; Estrada-Baltazar, A.; Gomez-Gonzalez, R. Informal collection, recycling and export of valuable waste as transcendent factor in the municipal solid waste management: A Latin-American reality. J. Clean. Prod. 2018, 182, 485–495.

[55] Serrona, K.R.B.; Yu, J.; Aguinaldo, E.; Florece, L.M. Developing a monitoring and evaluation framework to integrate and formalize the informal waste and recycling sector: The case of the Philippine National Framework Plan. Waste Manage. Res. 2014, 32(9), 882–895.

[56] Lebersorger, S.; Beigl, P. Municipal solid waste generation in municipalities: Quantifying impacts of household structure, commercial waste and domestic fuel. Waste Manage. 2011, 31, 1907–1915.

[57] Erses Yay, A.S. Application of life cycle assessment (LCA) for municipal solid waste management: A case study of Sakarya. J. Clean. Prod. 2015, 94, 284–293.

[58] Soltani, A.; Sadiq, R.; Hewage, K. The impacts of decision uncertainty on municipal solid waste management. J. Environ. Manage. 2017, 197, 305–315.

[59] Allesch, A.; Brunner, P.H. Assessment methods for solid waste management: A literature review. Waste Manage. Res. 2014, 32, 461–473.

[60] Lella, J.; Mandla, V.R.; Zhu, X. Solid waste collection/transport optimization and vegetation land cover estimation using Geographic Information System (GIS): A case study of a proposed smart-city. Sustain. Cities Soc. 2017.

[61] Kanchanabhan, T.E.; Abbas Mohaideen, J.; Srinivasan, S.; Kalyana Sundaram, V.L. Optimum municipal solid waste collection using geographical information system (GIS) and vehicle tracking for Pallavapuram municipality. Waste Manage. Res. 2011, 29(3), 323–339.

[62] Zamorano, M.; Molero, E.; Grindlay, A.; Rodríguez, M.L.; Hurtado, A.; Calvo, F.J. A planning scenario for the application of geographical information systems in municipal waste collection: A case of Churriana de la Vega (Granada, Spain). Resour. Conserv. Recy. 2009, 54, 123–133.

[63] Khan, D.; Samadder, S.R. Municipal solid waste management using Geographical Information System aided methods: A mini review. Waste Manage. Res. 2014, 32(11), 1049–1062.

[64] Zsigraiova, Z.; Semiao, V.; Beijoco, F. Operation costs and pollutant emissions reduction by definition of new collection scheduling and optimization of MSW collection routes using GIS. The case study of Barreiro, Portugal. Waste Manage. 2013, 33, 793–806.

[65] Faccio, M.; Persona, A.; Zanin, G. Waste collection multi objective model with real time traceability data. Waste Manage. 2011, 31, 2391–2405.

[66] Bing, X.; de Keizer, M.; Bloemhof-Ruwaard, J.M.; van der Vorst, J.G.A.J. Vehicle routing for the eco-efficient collection of household plastic waste. Waste Manage. 2014, 34, 719–729.

[67] Das, S.; Bhattacharyya, B.K. Optimization of municipal solid waste collection and transportation routes. Waste Manage. 2015, 43, 9–18.

[68] Son, L.H.; Louati, A. Modeling municipal solid waste collection: A generalized vehicle routing model with multiple transfer stations, gather sites and inhomogeneous vehicles in time windows. Waste Manage. 2016, 52, 34–49.

[69] Malakahmad, A.; Md Bakri, P.; Md Mokhtar, M.R.; Khalil, N. Solid waste collection routes optimization via GIS techniques in Ipoh city, Malaysia. Procedia Eng. 2014, 77, 20–27.

[70] Abdelli, I.S.; Abdelmalek, F.; Djelloul, A.; Mesghouni, K.; Addou, A. GIS-based approach for optimised collection of household waste in Mostaganem city (Western Algeria). Waste Manage. Res. 2016.

[71] MMAyA Diagnóstico de la gestión de residuos sólidos en el Departamento de La Paz, Dirección general de gestión integral de residuos sólidos. [In Spanish].; 2012;

[72] Ferronato, N.; Gorritty Portillo, M.A.; Guisbert Lizarazu, E.G.; Torretta, V.; Bezzi, M.; Ragazzi, M. The municipal solid waste management of La Paz (Bolivia): Challenges and opportunities for a sustainable development. Waste Manage. Res. 2018, 36, 288–299.

[73] Swisscontact, 2008 Estudio de gestión de residuos sólidos reciclables, para la ciudad de La Paz. Informe final [In Spanish]

[74] Ferronato, N.; Ragazzi, M.; Gorritty Portillo, M.A.; Guisbert Lizarazu, E.G.; Viotti, P.; Torretta, V. How to improve recycling rate in developing big cities: An integrated approach for assessing municipal solid waste collection and treatment scenarios. Environ. Dev. 2019, 29, 94–110.

[75] Trulli, E.; Ferronato, N.; Torretta, V.; Piscitelli, M.; Masi, S.; Mancini, I. Sustainable mechanical biological treatment of solid waste in urbanized areas with low recycling rates. Waste Manage. 2018, 71, 556–564.

[76] Scaglia, B.; Salati, S.; Di Gregorio, A.; Carrera, A.; Tambone, F.; Adani, F. Short mechanical biological treatment of municipal solid waste allows landfill impact reduction saving waste energy content. Bioresour. Technol. 2013, 143, 131–138.

[77] EPA, 2015. Waste Materials Density Data. EPA Victoria Environmental Protection Authority Victoria. https//www.epa.vic.gov.au/business-and-industry/lower-your impact/ /media/Files/bus/EREP/docs/wastematerials-densities-data.pdf

[78] Palanivel, T.M.; Sulaiman, H. Generation and Composition of Municipal Solid Waste (MSW) in Muscat, Sultanate of Oman. APCBEE Procedia 2014, 10, 96–102.

[79] EPA, 2015. Waste Weight Determination. United States Environmental Protection Agency.

[80] ARPA Annuario regionale dei dati ambientali [In Italian]. Arpa Emilia Romagna. $https//www.arpae.it/cms3/documenti/_{c}erca_{d}oc/stato_{a}mbiente/annuario2006/2006_{0}8_{c}ap5.pdf$ 2006.

[81] ANPA, 2001. Definizione di standard tecnici di igiene urbana [In Italian]. Agenzia Nazionale per la Protezione Ambientale (ARPA) e Osservatorio Nazionale sui Rifiuti (ONR)

[82] ISPRA, 2018. Rapporto Rifiuti Urbani [In Italian]

[83] Gallardo, A.; Bovea, M.D.; Colomer, F.J.; Prades, M.; Carlos, M. Comparison of different collection systems for sorted household waste in Spain. Waste Manage. 2010, 30, 2430–2439.

[84] Hartmann, H.; Møller, H.B.; Ahring, B.K. Efficiency of the anaerobic treatment of the organic fraction of municipal solid waste: Collection and pretreatment. Waste Manage. Res. 2004, 22, 35–41.

[85] Saha, J.K.; Panwar, N.; Singh, M. V. An assessment of municipal solid waste compost quality produced in different cities of India in the perspective of developing quality control indices. Waste Manage. 2010, 30, 192–201.

[86] Rigamonti, L.; Grosso, M.; Giugliano, M. Life cycle assessment for optimising the level of separated collection in integrated MSW management systems. Waste Manage. 2009, 29, 934–944.

[87] Montejo, C.; Tonini, D.; Márquez, M. del C.; Fruergaard Astrup, T. Mechanical-biological treatment: Performance and potentials. An LCA of 8 MBT plants including waste characterization. J. Environ. Manage. 2013, 128, 661–673.

[88] Münnich, K.; Mahler, C.F.; Fricke, K. Pilot project of mechanical-biological treatment of waste in Brazil. Waste Manage. 2006, 26, 150–157.

[89] AMIU, 2014. Taranto Piano industriale dei servizi di igiene ambientale per il comune di Taranto: Elenco prezzi unitari. Contratto di servizio. Progetto definitivo [In Italian]

[90] ARPA Lazio, 2012. Tariffario delle prestazioni erogate dall'agenzia [In Italian]. Agenzia regionale protezione ambientale del Lazio - ARPA Lazio.

[91] Comune di Firenze, 2010. Elenco prezzi unitari e analisi dei costi [In Italian]. Ufficio Gestione Rifiuti e Bonifica Siti Contaminati.

[92] ENIA, 2009. Tariffario igiene ambientale [In Italian]

[93] Comune di Langhirano, 2007. Verbale di deliberazione del consiglio comunale: approvazione del piano nanziario del servizio di gestione dei ri uti [In Italian]

[94] Comune di Grammichele, 2014. Progetto tecnico: gestione del servizio di igiene urbana del comune di Grammichele [In Italian]. Ufficio Ambiente.

[95] Regione Toscana L'impianto di compostaggio di Case Passerini (Sesto Fiorentino) [In Italian]. Bollettino Ufficiale della Regione Toscana n.42, 17-10-2017 2007.

[96] Mollica, A.; Vilella, A. 2015. Il riciclo della frazione organica dei rifiuti solidi urbani per l'allevamento del lombrico [In Italian]. Azianda Regionale per lo Sviluppo dell'agricoltura Calabrese - ARSAC Reggio Calabria

[97] ARPA Lombardia, 2012. Report impianti di trattamento dei rifiuti nella Provincia di Como. Agenzia Nazionale per la Protezione Ambientale (ARPA) - ARPA Lombardia.

[98] GENESU, 2012 Il Compost di qualità - COMPOSTA. Impianto di Compostaggio di Pietramelina, Perugia [In Italian]. Gestione servizi nettezza urbana - Igiene urbana di Perugia.

[99] Banar, M.; Cokaygil, Z.; Ozkan, A. Life cycle assessment of solid waste management options for Eskisehir, Turkey. Waste Manage. 2009, 29, 54–62.

[100] Lima, P.D.M.; Colvero, D.A.; Gomes, A.P.; Wenzel, H.; Schalch, V.; Cimpan, C. Environmental assessment of existing and alternative options for management of municipal solid waste in Brazil. Waste Manage. 2018, 78, 857–870.

[101] Kinobe, J.R.; Bosona, T.; Gebresenbet, G.; Niwagaba, C.B.; Vinnerås, B. Optimization of waste collection and disposal in Kampala city. Habitat Int. 2015, 49, 126–137.

[102] Sharholy, M.; Ahmad, K.; Vaishya, R.C.; Gupta, R.D. Municipal solid waste characteristics and management in Allahabad, India. Waste Manage. 2007, 27, 490–496.

[103] Erfani, S.M.H.; Danesh, S.; Karrabi, S.M.; Shad, R. A novel approach to find and optimize bin locations and collection routes using a geographic information system. Waste Manage. Res. 2017, 35(7), 776–785.

[104] Ferronato, N.; Torretta, V. Waste Mismanagement in Developing Countries: A Review of Global Issues. Int. J. Env. Res. Pub. He. 2019, 16(6), 1060.

[105] Gutberlet, J.; Baeder, A.M.; Pontuschka, N.N.; Felipone, S.M.N.; dos Santos, T.L.F. Participatory research revealing the work and occupational health hazards of cooperative recyclers in Brazil. Int. J. Env. Res. Pub. He. 2013, 10, 4607–4627.

[106] Simatele, D.M.; Dlamini, S.; Kubanza, N.S. From informality to formality: Perspectives on the challenges of integrating solid waste management into the urban development and planning policy in Johannesburg, South Africa. Habitat Int. 2017, 63, 122–130.

[107] Sasaki, S.; Araki, T. Employer-employee and buyer-seller relationships among waste pickers at final disposal site in informal recycling: The case of Bantar Gebang in Indonesia. Habitat Int. 2013, 40, 51–57.

[108] Keramitsoglou, K.M.; Tsagarakis, K.P. Public participation in designing the recycling bins to encourage recycling. Sustainability 2018, 10(4), 1240.

[109] Vicente, P.; Reis, E. Factors influencing households' participation in recycling. Waste Manage. Res. 2008, 26(2), 140–146.

[110] Yukalang, N.; Clarke, B.; Ross, K. Solid waste management solutions for a rapidly urbanizing area in Thailand: Recommendations based on stakeholder input. Int. J. Env. Res. Pub. He. 2018, 15(7), 1302.

[111] Tavares, G.; Zsigraiova, Z.; Semiao, V.; Carvalho, M.G. Optimisation of MSW collection routes for minimum fuel consumption using 3D GIS modelling. Waste Manage. 2009, 29, 1176–1185.

[112] Farahbakhsh, A.; Forghani, M.A. Sustainable location and route planning with GIS for waste sorting centers, case study: Kerman, Iran. Waste Manage. Res. 2019, 37(3), 287–300.

[113] Nguyen-Trong, K.; Nguyen-Thi-Ngoc, A.; Nguyen-Ngoc, D.; Dinh-Thi-Hai, V. Optimization of municipal solid waste transportation by integrating GIS analysis, equation-based, and agent-based model. Waste Manage. 2017, 59, 14–22.

[114] Bosompem, C.; Stemn, E.; Fei-Baffoe, B. Multi-criteria GIS-based siting of transfer station for municipal solid waste: The case of Kumasi Metropolitan Area, Ghana. Waste Manage. Res. 2016, 34(10), 1054–1063.

[115] Geng, Y., Liu, K., Xue, B., Fujita, T., 2013. Creating a "green university" in China: A case of Shenyang University. J. Clean. Prod. 61, 13–19.

[116] Moreira, R., Malheiros, T.F., Alfaro, J.F., Cetrulo, T.B., Ávila, L. V., 2018. Solid waste management index for Brazilian Higher Education Institutions. Waste Manage. 80, 292–298.

[117] Smyth, D.P., Fredeen, A.L., Booth, A.L., 2010. Reducing solid waste in higher education: The first step towards "greening" a university campus. Resour. Conserv. Recy. 54, 1007–1016.

[118] Zhang, N., Williams, I.D., Kemp, S., Smith, N.F., 2011. Greening academia: Developing sustainable waste management at Higher Education Institutions. Waste Manage. 31, 1606–1616.

[119] Espinosa, R.M., Turpin, S., Polanco, G., De laTorre, A., Delfín, I., Raygoza, I., 2008. Integral urban solid waste management program in a Mexican university. Waste Manage. 28, S27–S32.

[120] Fagnani, E., Guimarães, J.R., 2017. Waste management plan for higher education institutions in developing countries: The Continuous Improvement Cycle model. J. Clean. Prod. 147, 108–118.

[121] Barros, R.M., Filho, G.L.T., Moura, J.S., Pieroni, M.F., Vieira, F.C., Lage, L.R., Mohr, G.S., Bastos, A.S., 2013. Design and implementation study of a Permanent Selective Collection Program (PSCP) on a University campus in Brazil. Resour. Conserv. Recy. 80, 97–106.

[122] Bringhenti, J.R., Zandonade, E., Günther, W.M.R., 2011. Selection and validation of indicators for programs selective collection evaluation with social inclusion. Resour. Conserv. Recy. 55, 876–884.

[123] Dwivedy, M., Mittal, R.K., 2013. Willingness of residents to participate in e-waste recycling in India. Environ. Dev. 6, 48–68.

[124] Ramaswami, A., Baidwan, N.K., Nagpure, A.S., 2016. Exploring social and infrastructural factors affecting open burning of municipal solid waste (MSW) in Indian cities: A comparative case study of three neighborhoods of Delhi. Waste Manage. Res. 34(11), 1164–1172.

[125] Zen, I.S., Noor, Z.Z., Yusuf, R.O., 2014. The profiles of household solid waste recyclers and non-recyclers in Kuala Lumpur, Malaysia. Habitat Int. 42, 83–89.

[126] Refsgaard, K., Magnussen, K., 2009. Household behaviour and attitudes with respect to recycling food waste - experiences from focus groups. J. Environ. Manage. 90, 760–771.

[127] Ferreira, S., Cabral, M., De Jaeger, S., Da Cruz, N.F., Simões, P., Marques, R.C., 2017. Life cycle assessment and valuation of the packaging waste recycling system in Belgium. J. Mater. Cycles Waste 19, 144–154.

[128] Gallardo, A., Carlos, M., Colomer, F.J., Edo-Alcón, N., 2018. Analysis of the waste selective collection at drop-off systems: Case study including the income level and the seasonal variation. Waste Manage. Res. 36, 30–38.

[129] Cobbinah, P.B., Erdiaw-Kwasie, M.O., Amoateng, P., 2015. Rethinking sustainable development within the framework of poverty and urbanisation in developing countries. Environ. Dev.

[130] Ragazzi, M., Catellani, R., Rada, E.C., Torretta, V., Salazar-Valenzuela, X., 2014. Management of municipal solid waste in one of the Galapagos islands. Sustainability 6(12), 9080–9095.

[131] León-Fernández, Y., Gomera, A., Antúnez, M., Martínez-Escrich, B., Villamandos, F., Vaquero, M., 2018. Enhancing environmental management in universities through participation: the case of the University of Córdoba. J. Clean. Prod. 172, 4328–4337.

[132] Masood, M., Barlow, C.Y., 2013. Framework for integration of informal waste management sector with the formal sector in Pakistan. Waste Manage. Res. 31, 93–105.

[133] Sembiring, E., Nitivattananon, V., 2010. Sustainable solid waste management toward an inclusive society: Integration of the informal sector. Resour. Conserv. Recy. 54, 802–809.

[134] Longe EO (2012) Healthcare waste management status in Lagos State, Nigeria: a case study from selected healthcare facilities in Ikorodu and Lagos metropolis. Waste Management & Research 30(6): 562-571.

[135] Idowu I, Alo B, Atherton W, and Al Khaddar R. (2013) Profile of medical waste management in two healthcare facilities in Lagos, Nigeria: a case study. Waste Management & Research 31(5): 494-501.

[136] Mol MP, Gonçalves JP, Silva EA, Scarponi CF, Greco DB, Cairncross S, and Heller L (2016). Seroprevalence of hepatitis B and C among domestic and healthcare waste handlers in Belo Horizonte, Brazil. Waste Management & Research 34(9): 875-883.

[137] Ali M, Wang W, Chaudhry N, and Geng Y (2017) Hospital waste management in developing countries: a mini review. Waste Management & Research 35(6): 581-592.

[138] Koolivand A, Mahvi AH, Alipoor V, Azizi K, and Binavapour M. (2012) Investigating composition and production rate of healthcare waste and associated management practices in Bandar Abbass, Iran. Waste Management & Research, 30(6), 601-606.

[139] Haylamicheal ID, Dalvie MA, Yirsaw BD, and Zegeye HA (2011) Assessing the management of healthcare waste in Hawassa city, Ethiopia. Waste Management & Research 29(8): 854-862.

[140] de Titto E, Savino AA, and Townend WK (2012) Healthcare waste management: the current issues in developing countries. Waste Management & Research 30(6): 559–561

[141] Akpieyi A, Tudor TL, and Dutra C (2015) The utilisation of risk-based frameworks for managing healthcare waste: A case study of the National Health Service in London. Safety Science 72: 127-132.

[142] Minoglou M, Gerassimidou S., and Komilis D (2017). Healthcare Waste Generation Worldwide and Its Dependence on Socio-Economic and Environmental Factors. Sustainability 9(2): 220.

[143] Ferreira JA, Bila DM, Ritter E, and Braga AC (2012) Chemical healthcare waste management in small Brazilian municipalities. Waste Management & Research, 30(12): 1306-1311.

[144] Chaerul M, Tanaka M, and Shekdar AV (2008) A system dynamics approach for hospital waste management. Waste management 28(2): 442-449.

[145] Elimelech E, Ayalon O, and Flicstein B (2011) Hazardous waste management and weight-based indicators—The case of Haifa Metropolis. Journal of hazardous materials 185(2-3): 626-633.

[146] Windfeld ES and Brooks MSL (2015) Medical waste management–A review. Journal of environmental management 163: 98-108.

[147] Diaz LF, Eggerth LL, Enkhtsetseg SH, and Savage GM (2008) Characteristics of healthcare wastes. Waste management 28(7): 1219-1226.

[148] Sartaj M, and Arabgol R (2015) Assessment of healthcare waste management practices and associated problems in Isfahan Province (Iran). Journal of Material Cycles and Waste Management 17(1): 99-106.

[149] Maamari O, Brandam C, Lteif R, and Salameh D. (2015) Health Care Waste generation rates and patterns: The case of Lebanon. Waste management 43: 550-554.

[150] Barbosa FCL, and Mol MPG (2018) Proposal of indicators for healthcare waste management: Case of a Brazilian public institution. Waste Management & Research 36(10): 934-941.

[151] Tesfahun E, Kumie A and Beyene A (2016) Developing models for the prediction of hospital healthcare waste generation rate. Waste Management & Research. 34(1): 75-80.

[152] Moreira AMM and Günther WMR (2013). Assessment of medical waste management at a primary health-care center in São Paulo, Brazil. Waste Management 33(1): 162-167.

[153] Caniato M, Tudor T, and Vaccari M (2015) International governance structures for health-care waste management: A systematic review of scientific literature. Journal of Environmental Management 153: 93-107.

[154] Lee S, Vaccari M and Tudor T (2016) Considerations for choosing appropriate healthcare waste management treatment technologies: A case study from an East Midlands NHS Trust, in England. Journal of Cleaner Production 135: 139-147.

[155] Geng Y, Ren WX, Xue B, Fujita T, Xi FM, Liu Y, and Wang ML (2013). Regional medical waste management in China: a case study of Shenyang. Journal of Material Cycles and Waste Management, 15(3), 310-320.

[156] Thakur V and Ramesh A (2015). Healthcare waste management research: A structured analysis and review (2005–2014). Waste Management & Research 33(10): 855-870.

[157] WHO - World Health Organization (2014) Safe management of wastes from health-care activities. Chartier Y (Ed.)

[158] Ananth, A. P., Prashanthini, V., and Visvanathan, C. (2010) Healthcare waste management in Asia. Waste Management 30(1): 154-161.

[159] El-Salam MMA (2010) Hospital waste management in El-Beheira Governorate, Egypt. Journal of environmental management 91(3): 618-629.

[160] Caniato M, Tudor TL, and Vaccari M (2016) Assessment of health-care waste management in a humanitarian crisis: A case study of the Gaza Strip. Waste Management 58: 386-396.

[161] Doylo T, Alemayehu T and Baraki N (2019). Knowledge and Practice of Health Workers about Healthcare Waste Management in Public Health Facilities in Eastern Ethiopia. Journal of community health 44(2): 284-291.

[162] Wilson DC, Rodic L, Cowing MJ, Velis CA, Whiteman AD, Scheinberg A, ... and Oelz B (2015) 'Wasteaware'benchmark indicators for integrated sustainable waste management in cities. Waste Management 35: 329-342.

[163] Wilson DC, Rodic L, Scheinberg A, Velis CA and Alabaster G (2012) Comparative analysis of solid waste management in 20 cities. Waste Management & Research 30(3): 237-254.

[164] Swisscontact (2003) Diagnóstico de los residuos sólidos generados en los establecimientos de salud del municipio de la paz. [In Spanish].

[165] Niyongabo E, Jang YC, Kang D and Sung K (2019). Generation, management practices and rapid risk assessment of solid medical wastes: a case study in Burundi. Journal of Material Cycles and Waste Management: 1-12.

[166] Shinee E, Gombojav E, Nishimura A, Hamajima N and Ito K (2008). Healthcare waste management in the capital city of Mongolia. Waste management 28(2): 435-441.

[167] Shanmugasundaram J, Soulalay V, and Chettiyappan V (2012) Geographic information system-based healthcare waste management planning for treatment site location and optimal transportation routeing. Waste Management & Research 30(6): 587-595.

[168] Hadipour M, Saffarian S, Shafiee M, and Tahmasebi S (2014) Measurement and management of hospital waste in southern Iran: a case study. Journal of Material Cycles and Waste Management 16(4): 747-752.

[169] Cesaro A, and Belgiorno V (2017) Sustainability of Medical Waste Management in Different Sized Health Care Facilities. Waste and Biomass Valorization 8(5): 1819-1827.

[170] Manga VE, Forton OT, Mofor LA and Woodard R (2011). Health care waste management in Cameroon: A case study from the Southwestern Region. Resources, Conservation and Recycling 57: 108-116.

[171] Farzadkia M, Moradi A, Mohammadi MS and Jorfi S (2009). Hospital waste management status in Iran: a case study in the teaching hospitals of Iran University of Medical Sciences. Waste Management & Research 27(4): 384-389.

[172] Sasu S, Kümmerer K and Kranert M (2012). Assessment of pharmaceutical waste management at selected hospitals and homes in Ghana. Waste Management & Research 30(6): 625-630.

[173] Khammaneechan P, Okanurak K, Sithisarankul P, Tantrakarnapa K, and Norramit P (2011) Effects of an incinerator project on a healthcare-waste management system. Waste Management & Research 29(10): S91-S96.

[174] Hossain MS, Santhanam A, Norulaini NN, and Omar AM (2011) Clinical solid waste management practices and its impact on human health and environment–A review. Waste management 31(4): 754-766.

[175] Lu C, You JX, Liu HC and Li P (2016). Health-care waste treatment technology selection using the interval 2-tuple induced TOPSIS method. International journal of environmental research and public health 13(6): 562.

# Chapter 5

# Implementation of international cooperation projects

*- It seams always impossible until it's done -*
*N. Mandela*

## Introduction

In this Chapter, two development cooperation projects submitted to international lenders are introduced. The projects were submitted thanks to the theoretical and technical studies implemented during the Ph.D. research and presented in this document. Both proposals were submitted in 2018/2019 in cooperation with the NGO COOPI, the GAMLP, and with the local University (UMSA).

The Chapter is divided in two sections, where the aim of the projects, the partners involved, the objectives and expected results are provided, as well as the expected impacts of the actions. In the first section, the project submitted to the AICS is presented. The project has been approved in June 2019 and financed in September 2019, at the end of the Ph.D. research period. In the second section, the project submitted to the EC is introduced. The concept note of the project has been submitted in April 2019, and approved in June 2019. Then, the submission of the full proposal was draft and submitted at the end of July 2019. The project was not approved due to the lack of experience of the Bolivian NGO in the management of financial resources.

The last section of the chapter discusses the pros and cons of the projects, highlighting which parts of the research were useful for the submission and which deficiencies should be covered, underlining the success of the approach used for involving local partners and implementing the technical knowledge developed during the Ph.D. research.

## 5.1 Recycling, material recovery, research and information: the project financed by the AICS

The aim of the action is to introduce management models and appropriate technologies for improving the disposal of waste, according to the principles of the CE. The intervention is based in the city of La Paz, where the political and administrative conditions are suitable to implement integrated management models, because of the increasing environmental effects of the non-treated effluents, open dumps and open burning of MSW.

The GMALP is starting to take the first steps towards the implementation of new methodologies to appropriately manage the waste, applying pilot plans of SC, raising awareness among the citizens about environmental problems and experimenting new technologies for recycling. The project will provide technical/scientific support to the GMALP, with the introduction of new treatment systems, and the development of awareness and information campaigns. Hence, the activity will be implemented in collaboration with the two universities that cooparate during the Ph.D. research (UMSA and University of Insubria). Those universities will have the role of verifying and consolidating the functionalities of the newly introduced systems and supporting the scientific dissemination of the innovative technologies implemented.

The project was submitted to the AICS in Dicember 2018 and it was approved in June 2019. The title of the action is:

"*LaPazRecicla. Integrated waste management approaches in La Paz, Bolivia: development of new technologies to foster the CE*".

The goals of the project are related to:

- Improvement of the separated collections systems for paper, plastics, glass and metal implemented by the GMALP;
- Introduction of new technologies for energy recovery of non-recyclable waste (such as plastics, textiles, wood, cardboard, etc.);
- Application of innovative management models for special and/or hazardous waste, such as C&D waste.

The project wants to reduce the presence of C&DW open dumps in La Paz, promote green polices for the economic sustainability of the city, and raise awareness among the citizenship on the environmental problems related to the SWM. Furthermore, the action has the goal to foster income generation opportunities based on the re-use of the solid waste. The main impact of the project is related to increase the recycling rate in the city, which allows a lower ecologic footprint, and then a reduction in the $CO_{2-eq}$ emissions. The long-term purpose is to scale up the innovative pilot solutions proposed by the project into large scale industrial plants, so to consolidate the management models, and become a reference of best practices for the entire country and other Latin-American experiences.

### 5.1.1 Partners involved and SDGs of the project

#### Partners

The project has been submitted thanks to the cooperation of four actors: The NGO COOPI, the GAMLP and the two universities (University of Insubria - DiSTA and UMSA). COOPI, head of the project, is one of the largest and most important Italian NGOs. It works in 30 countries around the world, implementing more than 200 development and emergency projects in a year with civil society, public administrations, international and academic authorities. COOPI operates in contexts characterized by extreme poverty and socio-political or environmental fragility through an approach that links intervention in emergency situations with rehabilitation and community development, providing sustainable response in the long term, ensuring continuity between security, humanitarian assistance and development.

The GMALP is the beneficiary of the action. As autonomous local government, it is the local manager in the implementation of new development plans and in the management of the projects carried out within the city. Its contribution is fundamental in the long-term sustainability of the action introduced. It has an office dedicated to environmental management (Municipal Secretary for Environmental Management - SMGA), which deals with the issue of waste and therefore the various aspects of the action. In particular, the SMGA is specialized in SWM, it is involved in projects organized by international NGOs and by the national government, both in the field of municipal and industrial waste.

The two universities involved are the UMSA and the University of Insubria. The UMSA is the local technical partner, with the availability of laboratories, equipment, experienced engineers in the field of SWM and students. It has two specific institutes dedicated to the theme of action: IIDEPROQ - Research and Development institute of Chemical Processes and IQPAA - Deparment of Chemical and Environmental Engineering. UMSA participated in waste-related projects within the city, continuously supporting the municipal environmental management system and providing technical and consultative support to the GMALP and private entities.

The Insubria University, by the Department of Theoretical and Applied Sciences (DiSTA) support all the project activities. Its role is fundamental in providing qualified personnel and technical knowledge for research processing, technology transfer and application within the framework of the project. His contribution is key in monitoring the SWM system, in the direct connection between the local universities and the Government, carrying out the studies necessary to calculate the indicators of the general objective. Moreover, the project started thanks to the work implemented from 2016 thanks to the Ph.D. fellow.

#### SDGs

The action follows the objectives provided by the SDGs [2]. In particular (Figure 5.1):

- 11 - Making cities and human settlements inclusive, safe, durable and sustainable;
- 12 - Guaranteeing sustainable production and consumption patterns;
- 17 - Strengthen the means of implementation and renew the global partnership for sustainable development.

In particular, the specific targets considered are:

- 11.6 - By 2030, reduce the negative environmental impact per capita in cities, with particular attention to air quality and urban and other waste management (11.6.1 Proportion of solid urban waste regularly collected and with adequate final disposal of the total urban solid waste generated by the cities);
- 12.5 -: By 2030, substantially reduce waste production through prevention, reduction, recycling and re-use (12.5.1 National recycling rate, tons of recycled waste);
- 12.a - to help developing countries strengthen their scientific and technological capacities to move towards more sustainable models of consumption and production (12.a.1 Measures to support developing countries in research and development in the field of sustainable consumption and production and sustainable technologies for the environment);
- 17.7 - Technology. Promoting the development, transfer, and dissemination of environmentally friendly technologies in developing countries on favorable terms, even on preferential and preferential terms (17.7.1 Total amount of funding approved for developing countries to promote the development, transfer, and dissemination of environmentally sustainable technologies).


**Figure 5.1:** SDGs related to the project submitted to the AICS.

The indicators applied to the initiative derive from the Global Waste Management Outlook (GWMO) written by the International solid waste assosiation (ISWA) and by the United Nation Development Program (UNDP) [1]. In particular, the indicators used are:

- W2: Eliminate the uncontrolled open-air arrangement by 2020;
- W3: By 2030 ensure the sustainable management of any waste;
- W4: By 2030 reduce waste generation through the 3Rs principle;
- W6: creating "green jobs" through the circular economy.

Of these, the priority actions were identified: Guarantee the inclusion of the community within an integrated waste management system; Include energy from waste in national policies to support the development of renewable energy; Include legislation and regulations for waste management appropriate for local contexts.

Moreover, specifically for construction and demolition waste, the indicator proposed by the Construction Resource Initiatives Council (CRIC), cited in the GWMO, was considered: Achieving the goal of "zero waste" from construction and demolition to landfill by 2030. This indicator was taken into account because, as indicated by the GWMO, the appropriate management of construction and demolition waste (which represents 36% of the waste generated globally) is a priority aspect in the management of sustainable solid waste.

### 5.1.2 Logical framework: objectives, results and activities

#### General objective

The general objective is to contribute to improving the environmental sustainability of the city, on the management of solid waste, with particular attention to inorganic MSW and construction and demolition waste (C&DW).

Indicator 1 - General objective (I1.OG): Reduction of environmental impacts generated by the SWM system. In particular, the following impacts have been reduced:

- use of resources.
- energy consumption.
- The potential for global warming.
- The potential for reducing the ozone layer.

For its assessment, the methods specified by the ISO 14040/2006 and dedicated software for LCA will be used. The impacts calculated in the first six months of the project and at the end of the activities will be analyzed. Therefore, the apporach introduced in the previous chapter will be used for assessing the environmental impacts of the project.

#### Specific objective

The specific objective of the project is to introduce SWM systems that are inclusive, innovative, appropriate for the country context and that encourage the recovery of materials. The objective is mainly composed of four indicators:

- Indicator 1 (I1.OS): 100% ($2\,t\,d^{-1}$) increase in the formal SC of MSW compared to the total generated in the city. Currently, recycling is 0.2% (1 day). The data will be collected from the GMALP MRF.
- Indicator 2 (I2.OS): 2% ($50\,t\,d^{-1}$) of construction and demolition waste collected and processed in the formal management system. Currently 100% are in uncontrolled management.
- Indicator 3 (I3.OS): An innovative waste treatment system for the context is implemented in order to optimize the energy recovery from waste. Bolivia currently has no facilities and studies that aim to achieve this goal.
- Indicator 4 (I4.OS): At least one municipal law relating to the appropriate management of C&DW is approved. At the moment there is no specific law on the subject at municipal and national level.

**Expected results and activities**

The strategy is based on the development of four lines of action (corresponding to four main results) interconnected. The action will address the issue of (R1) C&DW treatment and recovery in the marketing for its re-use, (R2) the selection and recovery of recyclable waste, making collection more efficient as well as recycling. (R3) The non-recyclable waste selected thanks to R2 will be treated to transform it from waste material to raw material (R3), in the form of RDF or solid recovered fuel (SRF). The three results would generating and strengthening the dynamics of the CE, supported by communication and awareness-raising activities for the population, with particular focus to the youngest.Therefore, (R4) actions for strengthening knowledge and supporting the transfer of technologies at different levels are introduced, from the scientific to the management and technical-operational levels. This line of work will make it possible to consolidate the processes of R1, R2 and R3, and to guarantee their long-term sustainability. Three to five indicators were introduced for each result, in order to assess its improvements.

R1 - The negative environmental impact caused by the open disposal of C&DW has been reduced:

- I1.R1: A non-hazardous demolition and construction waste selection plant activated and in operation. There are no plants of this type in Bolivia.
- I2.R1: The 0.5% ($14\,t\,d^{-1}$) of C&DW is recycled. Currently 100% of the waste is sent to open dumps.
- I3.R1: A model of C&DW management that includes elements of collection, transport, selection and recovery of non-hazardous waste applied.

R2 - The efficiency and effectiveness of the urban waste selection process has improved:

- I1.R2: Three mechanical treatment plants for post-SC waste in operation. At the moment the only treatment facility available to the municipality is a conveyor belt for selection. There are no post-selection facilities.
- I2.R2: Increase in the annual sale of at least 100% of the material derived from the SC of recyclable waste.
- I3.R2: Increase of at least 1000 inhabitants per year sensitized in the subject of environmental sustainability and waste management. Currently, less than 1000 per year are informed.
- I4.R2: Inclusion of 5000 children in SC MSW collection programs.

R3 - A sustainable and integrated CE system of MSW has been implemented.

- I1.R3: A plant for the conversion of the waste selected waste into RDF has been implemented. Currently the waste-to-energy process is not carried out in Bolivia.
- I2.R3: Drafting of a document for the systematization and valorisation of the waste-to-energy process. Currently, Bolivian environmental regulations do not specify the characteristics of waste fuel.

- I3.R3: $1\,m^3\,d^{-1}$ of C&DW converted into "eco-bricks". Currently, the production process of bricks is carried out using virgin material.
- I4.R3: 30% of increase in average monthly economic income for the sale of recyclable waste.

R4 - Local technical skills related to innovative and developed methods for the exploitation of waste have been strengthened and spread.

- I1.R4: Engineers from the UMSA will participate at two international conferences in order to present the results of the activities implemented.
- I2.R4: Twenty engineers from the GMALP and private companies participate in technical courses on the issues of energy recovery of urban waste and recycling of C&DW with the participation of international professors. Currently, in Bolivia, there are no technical courses related to the subject.
- I3.R4: At least three research theses prepared on the issues of the CE of waste from C&DW and related to the energy recovery of waste, with relative evaluation of the environmental impacts reduced by these processes.
- I4.R4: 50 operators and volunteers related to the integrated life cycle of the CE are formed.
- I5.R4: Two scientific articles related to the topic of energy recovery of waste and reuse of C&DW waste published.

For each result, specific activities were planed to be implemented. For R1, the partners will (A1.1) support the preparation and issuing of the municipal Law for the appropriate management of C&DW and (A1.2) will construct a plant for the selection of C&DW. These activities were introduced due to specific requirements of the local government. The Ph.D. research did not support technically this part, but it assists the engagement between the local needs and the opportunities of research.

The activities for obtaining R2 were introduced both by the requirements of the GAMLP and the research conducted during the Ph.D. The first activity (A2.1) foresees the introduction of three treatment plants for the valorisation of urban waste from SC. At the same time, (A2.2) awareness and information campaigns will take place to increase participation of the population in MSW SC. This activity is the replication of the research conducted at municipal level and described in section 4.1. Finally, (A2.3) the organization of a competition for SC in elementary schools of La Paz will be supported. The last activity was implemented for the first time in 2018, and the local government would replicate it in order to continue the awareness campaigns at the schools.

For the third result, (A3.1) a plant to transform the selected non-recyclable waste for energy exploitation was considered to be introduced. It will be a small scale treatment plant for the application of researches at laboratory scale, in order to start the introduction of energy recovery policies in low-middle income countries. In parallel with the previous activity, (A3.2) a document to evaluate the pilot experimentation for the exploitation of the non-recyclable selected waste for the waste-to-energy directed at companies for possible future markets will be draft and provided to the local government. Finally, (A3.3) the C&DW treatment plant will produce the material for converting it in "eco-bricks", which will be formed at a small scale treatment facility. The whole result has been supported by the ideas and knowledge developed in the Ph.D., thanks to the cooperation with local stakeholders.

The last result is composed of four activities, which were supported by the Ph.D. research implemented at municipal level. In particular, the main activities reported from the Ph.D. to the project are the courses and seminars developed during the stay in Bolivia, as reported in section 4.4, and the LCA, which will be use as technical approach for the analysis of the project, as described in section 4.2. Therefore, the first activity (A4.1) will support the scientific dissemination of research results through conferences and scientific articles; the second activity (A4.2) will support the implementation of two specialization courses for the technicians involved in the waste management systems, while (A4.3) the third will support the organization of technical visits to Latin America for the engineers of the GAMLP. For supporting the implementation of the first three results, the fourth activity (A4.4) foresees the organization of two courses per year on staff collection operating procedures. Finallu, the LCA approach (A4.5) will be used for the study of environmental impacts avoided thanks to the project.

### 5.1.3 Impacts of the action and time for its implementation

The project will be implemented in 30 months, starting from September 2019. So, it will conclude in February 2022. The project wants to improve the SWM system of the city, a topic on which municipal institutions struggle to optimize their action, while the volume of waste progressively increases. This impact will be measured through the application of some standard environmental impact indicators, included in the evaluation package LCA: i) use of resources; ii) energy consumption; iii) global warming potential; iv) ozone layer reduction potential. To measure these indicators, specific software will be used, to be customized to the application context. This tool will be used during the project but at its conclusion it will be a useful tool to consolidate the environmental management of the GAMLP. This software will be acquired with the project, so at the moment the specific indicators reference data are not yet available.

The specific objective of the project is to introduce inclusive, innovative waste management systems, appropriate for the country context and that encourage the recovery of materials. To evaluate its implementation, four indicators will be used:

1) The quantity of waste deriving from SC will be measured, thus reducing the incidence on the city's landfills. The long-term benefits for the population will materialize in the reduction of landfill areas. Furthermore, the improvement of the selection procedures will allow the GAMLP to generate financial resources from the sale of the waste and from the reduction of waste streams entering the landfill. These resources can be used in favor of citizenship extending the areas covered by the service even in less well-off areas and creating new jobs.

2) The amount of waste from C&DW will be measured, which currently make up the majority of the city's waste, managed by the new model. The action will reduce the flow to open-air dumps, recovering a part of it, and also generating here a reduction in the spaces dedicated to them (at present almost all abusive). Also in this case, the new waste recovery capacity (previously not reused), will allow the generation of inputs for the GAMLP.

3) It will be verified that an innovative pilot system of treatment of non-recyclable

urban waste will work for their transformation into fuel. The benefit to the population of La Paz will be that an economy based on this waste will be activated. Furthermore, they will generate inputs in favor of the GAMLP through the sale of "eco-bricks" produced from C&DW.

4) The project will promote the generation and approval of legislation relating to the management and recovery of waste, which will contribute to the institutional nature of the issue and open up new opportunities for the CE based on waste.

These results will be the first in Bolivia, considering this action innovative for the whole country.

## 5.2 Social inclusion and innovation: the project submitted to the European Commission

The need for a local participatory environmental policy, particularly in SWM, has become an emergency due to the landslide that affected the Alpacoma sanitary landfill in January 2019. The GAMLP wants to generate a sustainable local public policy in environmental matters, involving the population and the university for supporting sustainable development. Taking into account this context and such issues, a project has been submitted to the EC. The title of the project is:

"*Ecojuventud. Young, innovation and circular economy against climate change*".

The proposal has been identified through a participatory process through meetings and previous activities that have been carried out during the three years in cooperation with the SMGA (Municipal Secretary of Environmental Management of the GAMLP), the NGO COOPI and the UMSA. The data and technical information introduced in the proposal are the result of the experience of the doctoral study and data derived from the previous experience of the NGO Swisscontact. The project has been built in agreement with the objectives and priorities of the call of the EC in Bolivia, in particular in relation to the overall objective:

- Improve the standard of living and respect for the rights of young people from a greater impact on public policies that are intended.

Two specific objectives are also involved in the project:

- Strengthen the knowledge, exercise and respect of the Economic, Social and Cultural Rights of young people;

- Contribute to ensure that public, local and / or national policies integrate and respond effectively to the needs of young people.

In relation to the sectors of the call, the proposal is linked, especially, with the environment and climate change sector, addressed by the implementation of the principles of the CE. The aim of the action is to support the participation of young people in the definition, execution and monitoring of public policies related to the environment and climate change from a local perspective. In particular, the SWM sector was involved and considered. The proposal is the consequence of the cooperation system built during the Ph.D. research: the activities and studies described in section 4.1, 4.3 and 4.4 , where the volunteers were involved as well as the activity of the informal sector was analyzed, are the main drivers of the proposal.

### 5.2.1 Project beneficiaries and main needs

The target group identified in the project is of young people (16-29 years old) from the metropolitan area of La Paz. These are divided into the following groups:

- Young people from the neighborhoods of La Paz (1500 young people).

- Volunteers and university students (1000 in three years).

- Informal collectors (300 women).
- Young entrepreneurs (50 professionals).

**Young people**

Currently many youth groups actively participate in activities towards sustainable development in La Paz. There are also studies and researches groups in different universities of the city, and groups that work as volunteers in the SMGA. Specifically, the proposal will involve a minimum of 180 young people who are part of associations (formal and informal) and active groups in the municipality, and of these 50 as group leaders.

Young people who participate in the information and awareness activities implemented by the action are also considered. The groups will be recognized and formalized as public policy actors thanks to the GAMLP and, thanks to that, they will be able to participate actively in the meetings of the Platform to listen and propose ideas and solutions related to municipal environmental policies.

The youth of La Paz do not have the capacities and the organization to constantly carry out campaigns and activities to monitor and implement local public policies. They do not have adequate preparation and knowledge about the arguments, circumstances and challenges to contribute with concrete actions against climate change and the groups are not formal or recognized in the municipality. Therefore, the activities are voluntarily conceived without a long-term plan and without obvious impacts on the community and the public policies of the mayor's office. This context also creates numerous situations of abandonment of voluntary work by the young people involved and distrust of young people interested in actively participating.

**Volunteers and university students**

They will participate in forums, workshops, seminars, theses and research on environmental issues and that are part of associations not recognized at the municipal level and that have supported awareness and information campaigns. Many students from different careers and universities in the city are already actively involved in academic events on environmental policies (i.e. UMSA recycle), and need support for valorising their efforts.

Students and volunteers do not always have or know the opportunities to obtain economic resources and technological knowledge, to develop research and studies on innovation, environment and sustainability. There are few opportunities to win scholarships and the possibilities of being able to access networks of international researchers.

**Informal collectors**

People or families that live thanks to the income they generate from the sale of recyclable solid waste, such as plastics, paper, cardboard and metals collected in the containers and in the garbage bags distributed in the streets. They live in conditions of poverty, do not have medical or retirement insurance and are not formally recognized at the municipal level.

Some citizens contribute to its collection, although the majority discriminate them due to their activity. The project would organize them thanks to the GAMLP and active participation in the Platform. The environmental leaders will be selected among the most outstanding women for the entire sector, and recognized as such by the Platform created by the project. The important role of these environmental leaders will be to transmit to the Platform the work and the needs that the informal collectors to first be recognized as key actresses of the CE sector, identifying possible synergies and improve the recycling system of the city.

Informal collectors are not organized at the municipal level and have no official recognition. They work in precarious situations and are not socially accepted by citizens and the municipality. In addition, most of the time they are families of immigrants from native villages who work together with their children.

**Young entrepreneurs**

These entrepreneurs work in different areas with innovative ideas that, thanks to project activities, will be selected, rewarded, trained and accompanied in their development. This target group will also actively participate in the development of local environmental policies thanks to an active collaboration in the Platform.

Young entrepreneurs do not have the necessary resources to conduct companies and to achieve a real impact on the realization of national and municipal policies on the environment. The ideas of green companies are numerous, as many are young people who try to start positioning an idea. However, bureaucracy, lack of knowledge, and initial investments are often an insurmountable obstacle for this group.

### 5.2.2 Objectives of the proposal

The project would provide solutions for strengthening the capacity of groups of beneficiaries with information, awareness, inclusion and support actions on environmental issues to enable them to play an important role in the implementation of municipal policies. For this purpose, a Municipal Platform will be organized that guarantees the effective participation of these organizations. The Platform, conformed with the active participation of GAMLP, Universities, groups of volunteers, students, citizens and youth of the neighborhoods, will be the place where these different actors can meet and discuss the implementation of municipal policies with the objective to find practical solutions and solve problems.

The young people of La Paz will be involved in environmental groups and associations through the its formal recognition, thanks to the action of the GAMLP. They will be supported in the organization of information and monitoring campaigns in the areas of the La Paz on environmental issues. The waste pickers, in particular women and the youngest, will be helped with technical strengthening and empowerment actions, recognizing their work with the cooperation of public institutions.

For young university students, the project will provide support for the implementation and valorization of scientific research and thesis on environmental issues, including research, workshops, events and academic articles from humanistic to scientific areas, thanks to the support of the UMSA. At the same time, the group of young entrepreneurs will be involved in activities with specific training and events.

With information campaigns, workshops, mass media and municipal environmental policies, citizens of La Paz will achieve a better access to information, improving citizen participation in environmental protection, recycling activities against climate change.

All target groups will be actively involved in the action through meetings, participatory workshops, training forums and discussion groups that will be developed jointly in neighborhoods, at university and public events. The proposals that will arise from these activities will be presented at the municipal level and to the municipal authorities at the meetings of the Platform. These principles are the same developed during the Ph.D. research and the cooperation experience developed during the years.

### 5.2.3 Results and actions

The project introduces actions to achieve two results:

- R1 - The groups of young leaders are formalized and participate in municipal policies on environmental issues, climate change, CE and SWM.
- R2 - Innovative plans have been implemented in CE and SWM issues based on the proposals of young people. Plans are defined as all the public strategic activities approved through participatory methodologies indispensable also for the creation of a support for green business and safe employment for the waste pickers.

To ensure effective youth participation, they will be trained on national and international laws and regulations with specific actions such as workshops, seminars, events and courses (among others). To achieve the benefit described in the first result, the project would formalize existing youth groups so that they can actively participate in the Municipal Platform on municipal policies, environmental issues and climate change.

To promote a public policy that connects the GAMLP and youth groups, the Discussion Platform on the design, execution and monitoring of environmental regulations will be organized and, at the same time, to recognize the social role of young environmental leaders, waste pickers solid will be involved in the SWM system of the city.

Achieved with these activities the results proposed by the proposal, two benefits can be generated at the end of the project, synthesized in two specific objectives:

- SO1: Promote responsible and informed citizens' participation in the design, execution and monitoring of municipal public policies on the issues of environment and climate change.
- SO2: Support the creation of green social enterprises and contribute to generating safe employment for MSW collection and separation in the city.

To achieve the first result (R1), the project foresees the carrying out of four activities, while for the second result (R2), three activities are planned, as detailed below.

**A1.1 Formalization of youth associations for the implementation of information and monitoring campaigns in the areas of the municipality on environmental issues**

With this activity the proposal would support groups and associations of young volunteers in information and public awareness activities. This part is direct consequence of the experiences conducted in the project UMSA-recycle (section 4.1).

The groups will be formed and organized to carry out campaigns, workshops and information seminars for citizens. The formalization consists of organizing these groups, so that they can have a statute, regulation and organization chart and thus be recognized by the GAMLP through an ad hoc registry (of youth associations in the environmental sector), essential for participation active in the activities of the Platform (described in A.1.3 of this section).

Once formally recognized, these groups will be organizers of actions related to environmental issues such as neighborhood cleaning, recycling and tree planting, among others. In addition, they will be able to support the formalization of other groups based on their experience and thus generate a multiplier effect in other neighborhoods so that they are recognized by the GAMLP. Specifically, at least once a year, a door-to-door sensitization activity will be organized in a total of 10 neighborhoods in the city of La Paz, where young people will distribute informative material on recycling modalities in the neighborhood and the importance of the collectors and waste pickers (formed and organized according to activity A.1.4), which may become agreements between the neighborhoods (which have directive and legal status) and these groups, generating a more efficient selective collection for waste pickers and formal collectors.

An important result of this activity will be the connection between formal and informal SWM actors, citizens, volunteers and waste pickers who generate trust and reciprocal respect. Environmental awareness campaigns will also be organized in each year of the project, where youth groups and associations in collaboration with the GAMLP through the SMGA and the UMSA will organize awareness activities for citizens, based on the interests and abilities of the young people involved. These activities will consist of awareness campaigns, fairs, information points in strategic places of the city and dissemination of informational material. The seminars will be moments not only for training but also for the exchange of experiences, ideas and development of environmental defense strategies.

#### A1.2 Formalization of discussion groups on municipal policies in environmental topics, involving neighborhood meetings, informal collectors, youth associations and students of the UMSA

The youth groups (A.1.1) will be formalized from the GAMLP, as formal recognition with registration in an ad hoc municipal list. These groups will also be protagonists of discussion meetings and environmental policy debates within the neighborhood councils of at least 10 neighborhoods in La Paz.

The young people will organize open meetings on the theme of environmental policies. The meetings, coordinated in collaboration with UMSA (especially with students and professors), will be attended by informal waste pickers, representatives of the groups and associations identified, representatives of neighborhoods and all interested citizens. The meetings of the neighborhood on the environmental issue will be the occasion to provide information to the citizens by the SMGA officials and to discuss the main problems at municipal level.

In these meetings, the presentation of proposals, needs, strategies through youth groups will be promoted to the Municipal Platform on environmental policies (A.1.3). It will be a way to give voice to citizens, understanding and sharing the needs of each neighborhood about environmental issues. To develop this dynamic, young people and other stakeholders in each neighborhood will be previously trained through workshops on the environmental policies of the municipality and what are its consequences on the population and the environment.

### A1.3 Organization and structuring of a municipal Public Discussion Platform with youth associations, on the design, execution and monitoring of environmental policies

The active participation of the groups involved in the action will be specified in the participation of a municipal Platform on public policies. The Platform will be an active space for participatory democracy, where the Mayor's Office will receive proposals from the actors involved in the environmental field and from citizens to define efficient and effective environmental policies. It will be also a space to discuss the achievements and results of existing municipal policies.

The Platform, as schematically depicted in Figure 5.2, will be a round table where representatives of youth groups identified in a municipal registry, collectors, representatives of students and academics, representatives of green companies and environmental leaders can participate. In the periodic meetings of the Platform, the needs of the citizens and the proposals and strategies for a better environmental protection in the city will be identified.

The proposals will be evaluated by the Mayor's officials so that they can be transformed into environmental policies based on feasibility criteria that the Platform will establish in a participatory manner. The Platform will also be responsible for monitoring the environmental policies that it approves and submits to the GAMLP. This platform will also aim to disseminate the activities of the "Ecojuventud" Program and disseminate the achievements of the actions, in order to raise awareness and empower young people.

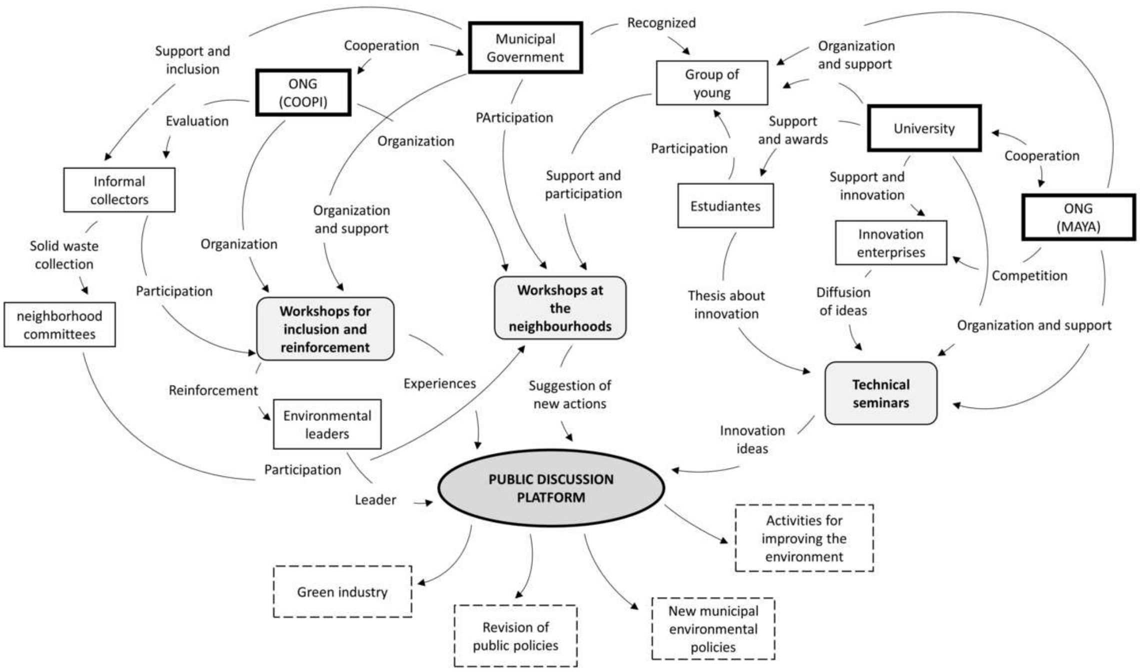


**Figure 5.2:** Theoretical scheme of the project submitted to the EC.

### A1.4 Support and empowerment of associations of MSW waste pickers of the city, for the training of young environmental leaders

A campaign will be carried out to gather information on the activity of informal collectors. About 300 collectors (mostly young women) are expected to be involved in the interviews. Based on the data collected, workshops will be organized to understand the needs of informal collectors, listening to their wishes and the challenges they face. About 150 collectors are expected to participate.

They will be trained in environmental issues and policies. Thanks to the results of the workshops, an expert in SWM and recycling will systematize the information and organize a plan for organizing the work of the collectors and segregators in 5 neighborhoods of La Paz (25 people divided into the 5 neighborhoods).

A workshop will also be dedicated to gender policies and especially to the role of women in environmental policies, with the participation of youth groups and staff and students of the UMSA and GAMLP officials, which will try to create a synergy with the International solid waste association (ISWA) - Women of Waste - campaign that coordinates and values the work of women in the recycling of solid waste worldwide [3]

Based on the plan developed, the groups of waste pickers will be organized in the 5 neighborhoods of the city, through dissemination campaigns (Activity 1.1) and distributing identifying material to the collectors (vests and a badge). Awareness campaigns and rapprochements between neighbors and waste pickers will be organized with the volunteers and the UMSA. The dissemination campaign work plan will increase the efficiency of the work of the collectors through agreements in areas with high-density buildings, interested in recycling, to facilitate the collection. The collectors and waste pickers that will be active in the 5 neighborhoods will be formally registered in the formal SWM system of the city, recognizing and giving value to their work.

Among the beneficiaries of this activity, will be recognized young leaders who can represent the group of the informal sector in the Platform (A.1.3). The leaders will also have the opportunity to travel to Cochabamba to learn about the successful model of waste collection in the city. Through the work of the project communicator, a media campaign to promote the profile and work of this target group will be organized. With these activities, the work of waste pickers is expected to be valued, in addition to providing them with tools so that, in the value chain, they can enter the recovery phase of solid waste through ventures that generate greater income and a better future. At the end of the project, the results will be presented to an international conference (in Europe), explaining the good practices achieved with the inclusion of waste pickers.

### A2.1 Organization of courses, forums, workshops and academic training activities on the topics of Climate Change and SWM, to discuss and promote ideas of young people

Courses and seminars will be organized on the topics of CE and climate change, training young people in the issue of environmental sustainability, innovation and entrepreneurship. Activities will also be organized on the issue of the inclusion of women in the SWM system and environmental sustainability.

Thanks to the collaboration with the UMSA, seminars will be organized for each year of the project with the participation of academics and national experts on environment and CE. Each seminar will identify a specific subject, such as SWM, climate change, ecological footprint, among others. The seminars will be organized for young people from universities and in general to interested people.

Young people and adults from different groups of volunteers will also be involved in these activities. Once a year, a 2-day interdisciplinary workshop on the environment will be organized with recognized teachers and round tables on local, national and international environmental policies (to learn and analyze successful models and good practices). Workshops will be organize, where the subject of environmental protection in municipal policies, with a focus on citizen participation and entrepreneurship, will be presented.

#### A2.2 Organization of national innovation competition for companies, with subsequent support of ideas

Two competitions will be organized, where Green ideas will participate to generate green enterprises that will be subsequently supported throughout the training and development phase. It is expected to support 20 new initiatives that arise from ideas, research and thesis, creating 2 new companies.

The UMSA will support the applied research of those initiatives that require improvement and new technologies. The GAMLP will be responsible for providing information, and eventually support the registration and authorization of these companies within the framework of current regulations.

#### A2.3 Implementation of scientific research and thesis on the topics of the CE and the SWM

Theses of students with innovative ideas (among students of the Universities of La Paz and El Alto) will be supported for environmental and social sustainability. The UMSA will be in charge of choosing the best students and the best ideas or master thesis studies. Through the Innovation Hub, research and technology will be supported for these theses.

Each year, one thesis will be awarded with support for its publication (publication costs will be covered), presenting their work in at least three Universities of other cities in Bolivia. Another product of the activity will be the production of two academic articles, written by researchers, in international journals on the project's achievements. Theses will be presented on the Platform to generate new ideas and put them into practice. With the Innovation Hub there will be a wide coverage so that engineering thesis can find new products, new materials and new processes in SWM.

### 5.2.4 Main impacts of the project

The most effective impact of the project refer to active citizen participation in local environmental policies, divided by groups of beneficiaries. In the second result, the project will support the implementation of plans, an action on about the CE and one on SWM with the active participation of the youth groups involved in the project.

The work of the Platform must be translated into actions and strategic lines in environmental issues, specifically in the sector of the CE and SWM in the City of La Paz. The most important feature of these plans is that they consider and take into account the active participation of the different groups of actors, with specific proposals and informed debates on environmental issues.

The youth groups will actively participate in the Platform through different steps. In the first instance, an effect linked to the recognition of informal youth groups in the city will be measured, as essential element for active and structured participation. The active participation of the informal collectors to the Platform can also be measured in different stages, each with an effect that can be measured over time. At the end of the project, at least 40 waste pickers have been involved in the official MSW collection system while at least 6 young environmental leaders are recognized at municipal and social level.

Moreover, at the end of the project, three theses will be awarded and two academic articles published. This indicator shows how thanks to a continuous work of professor training, important academic objectives will be achieved, converted into proposals for the Platform's plans. Meanwhile, the group of entrepreneurs will be involved in the plans of the Platform after a follow-up procedure activated by the project that will lead to indispensable intermediate effects for an active participation of the target group.

All this work and effects will lead to at least three management systems in environmental, cultural and Socio-economic issues have been approved through the Platform with participatory methodology, implying a positive effect on local environmental legislation, with a change focused on participatory democracy methodologies.

## 5.3 Discussion

The introduction of international cooperation projects represent one way for support sustainable development in terms of social inclusion, introduction of innovative systems, provision of resources and knowledge, share of experience and protection of the environment. The main focus is always population health, which can be directly or indirectly improved by the actions foreseen by the projects.

It should be underlined that the projects introduced by NGO and international funds are not aim in changing completely the framework where they are introduced, but are focused on the support for starting a changing process in behavior and habits taking into account local needs. Full scale plants or the introduction of massive improvements are not possible to achieve, since the economic support is minimal, if compared with the real requirements of city or country. Moreover, population behavior must also be taken into account since represent the main issue for introduce innovative systems.

International cooperation support is also required due to the global need to reduce environmental contamination, reduce inequity, improve population health, support the right of children and young women, as well as reduce the poverty and hunger. These changes are required due to the global issues that are affecting the environment and the economy at global level. As regard SWM, the main issues were reported in section 2.1, highlighting the needs of low income countries for improving the environmental and health conditions of cities and rural areas. Therefore, actions are required in low income countries for supporting sustainable development.

This section described two international cooperation projects submitted to international donors thanks to the support of NGO. It has been demonstrated how a Ph.D. study can help in drafting proposals that can be of interest for obtaining founding useful for the application of innovative solutions and academic research, improving public awareness and technical knowledge.

The first project represents the main output of the theoretical approach used during the four years of international cooperation between the Italian and Bolivian Universities presented in this Ph.D. thesis. The Academy, in collaboration with the NGO and local government, can support the introduction of proposals focused on the topics previously listed, in order to boost sustainability. The project financed by the AICS is the main example that can be provided to policy makers and international stakeholders to recognize the importance of the support of Ph.D. researches, international cooperation among various stakeholders, and the search of funds. These finding can be used for introducing projects focused on the CE, for supporting the introduction of a new economy of the waste, for improving ecological awareness among the population and for reducing environmental impacts due to SWM.

The second project, submitted to the EC, is the complementary of the first one, since it is mainly focused on the support of young citizens and innovative entrepreneurs in order to spread the CE principles. It is not a technical project, but social and centered in the development of the informal sector, which is of extreme importance locally in terms of material recovery and recycling. Therefore, both proposals, represent a complete and integrated action for supporting the city of La Paz in improving the SWM system.

On balance, this chapter shows the importance of the application of theoretical knowledge within a real case study for supporting the introduction of SWM projects. It demonstrates how international cooperation requires continues support and collaboration among various stakeholders, which can finally end with the submission of proposals. The Ph.D. research should therefore be considered as a potential support to government, NGO, developing countries and private companies for starting actions towards CE and sustainable development.

# Bibliography


[1] Wilson, D. C., Rodic, L., Modak, P., Soos, R., Carpintero, A., Velis, K., ... and Simonett, O. (2015). Global waste management outlook. UNEP.

[2] UNDP, 2016. 2030 Agenda and Objectives of Sustainable Development An opportunity for Latin America and the Caribbean.

[3] ISWA - International solid waste assosiation. Woman of Waste. Available online at: https://www.iswa.org/women-of-waste/

# Chapter 6

# Conclusions and remarks: Future perspectives and developments

*- International cooperation is a feeling of belonging to a global community,*
*a sense of responsibility towards sustainable development,*
*the call to do your part. -*

The rapid increase in population growth and urbanization spread the generation of solid waste at global level. In many developing countries, waste is scattered in urban centers or it is disposed off in open dump sites, affecting the environment and population health. The lack of infrastructures, technical knowledge, financial resources and public awareness are barriers that should be overcome for introducing sustainable SWM systems. Recycling and recovery of waste is imperative for reducing the waste of materials, although CE patterns specific for developing countries should be introduced.

The research conducted in La Paz demonstrated that its MSWM system is improved if compared with other developing big cities worldwide. The regulation system, the implementation of a sanitary landfill and of recycling activities, as well as the presence of a structured management system and the involvement of the population, allow considering La Paz as a good case study for introducing CE policies and plans. Anyhow, some issues were detected, in particular after the emergency of the collapse of the final disposal site that affected the good compliance of the SWM system of the city. Solutions must be implemented in short terms, in order to avoid future emergencies.

The research conducted suggests the implementation of the CE principles in La Paz: including the informal recycling sector into the SWM, introducing pre-treatment systems before landfilling, and apply new form of SC both for MSW non-hazardous and hazardous waste for reducing the waste inflow into the landfill and valorizing the materials. Such options were carefully assessed in terms of environmental, economic and social impacts. In particular, the research supported the local government of La Paz for assessing the main issues of the MSWM system of the city for introducing international cooperation projects about CE and sustainable SWM. The objectives of the research were mainly three:

- Provide an integrated approach for planning sustainable SWM systems in developing big cities of Latin America.

- Demonstrate the importance of the inclusion of the informal sector in the formal SWM system for improving the recycling activities.

- Draft an international cooperation project for introducing new appropriate technologies and sensitivity campaigns for boosting CE.

Therefore, the research explores different methods and studies for planning SWM systems in developing cities, with La Paz as case study. Seven steps were introduced by the application of technical methods and tools:

- Introduction of MSWM indicators, such as the WBI, in order to evaluate the current system and its developments during the years.

- Evaluation the opinion of local experts and stakeholders in order to assess their technical opinion about new SWM scenarios in function of their experience and expertise.

- Application of MCDA of future scenarios considering quantitative and qualitative data, in order to evaluate the main challenges and opportunities in the application of new SWM systems.

- Assessment of the opinion of local citizens through social surveys at municipal level, in order to understand the recycling behavior of the population and the type of waste selected.

- The application of LCA for evaluating the global environmental impacts due to solid waste collection, treatment and final disposal.

- Introduction spatial analysis through GIS for supporting the analysis of the collection options that can be introduced at municipal level, taking into account local SWM activities and options.

- Implementation of SC pilot actions in public areas, such as the university, in order to evaluate main issues and barriers for introducing recycling plans.

- Finally, the application of HWM indicators, that can be replicated for other solid waste fractions, required for considering other SWM systems hazardous of the environment.

All these methods and studies were applied within the Ph.D. research, for achieving the three main objectives of the thesis.

The results obtained suggest that informal recycling activities largely contribute to the MSWM sector. The social survey at municipal level reported that the informal sector is just included by a considerable part of the population, demonstrating that the population can be ready for implementing waste separation strategies thanks to the activity of the waste pickers. These finding were also supported by the results obtained with the SC system implemented at the University, since the good results in terms of SC rate were obtained due to the habit in SWM. The results obtained by the LCA provided also good indications about the best and worst MSWM options in terms of environmental impacts, suggesting that recycling allow reducing the GWP and that the activity of the informal sector contributing to this achievement. At the same time, the use of GIS allows demonstrating that the informal sector reduces MSW collection routes and investment costs if compared with a complete SC system, reducing the distances traveled by compactor trucks.

The methods and results obtained were used for drafting and submitting proposals to international donors in order to implement development cooperation projects. The Ph.D. research therefore end with the application of practical proposals for solving the SWM issues detected in La Paz. The methods theoretically applied for the Ph.D. research were used for drafting projects about CE in order to provide an effective positive impact to the municipality. Therefore, the three years research provided a real output that can be measured in the next two years.

The novelty of the research consist mainly in the application of integrated methods for the analysis of the SWM system in a specific context (La Paz, Bolivia) in order to evaluate the potentiality of the CE in a developing city. The results obtained should be considered unique in its gender, since the whole approach, as well as the cooperation system involved, were applied for the submission and application of the international cooperation projects described in this manuscript, one of them financed and effectively started in September 2019. Therefore, the Ph.D. contributed directly to the theoretical and practical application of technical tools useful for supporting sustainable development in low-income regions, with the aim to introduce actions towards the CE.

**Future developments**

First of all, the future developments of the research are focused on the implementation of the projects introduced thanks to the Ph.D. The analysis will focus on topics that were not explored by the research, in order to enlarge the subjects assessed in La Paz. Two main waste streams will be evaluated: the C&DW and the WtE opportunities of non-recyclable waste after SC in MRF. Therefore, the future research will be focused on the C&DW management, in order to collect and recycle the waste produced by the construction activity. Meanwhile, the calorific power of the non-recyclable MSW after SC, as well its physio-chemical composition, will be assessed in order to evaluate its potential market at national level, focusing on its recovery instead of final disposal. These studies will be implemented for the first time in Bolivia, supporting sustainable development and the CE principles.

Secondly, the approach used for the Ph.D. research should be replicated in other Latin America areas, in order to evaluate the feasibility of its implementation in other similar contexts, as well as in other developing cities with similar issues of La Paz. Countries like Perú, Ecuador, Colombia and Paraguay suffer similar problems in SWM, which can be overcome only thanks to the implementation of new technical solutions.

Finally, the main challenge is the inclusion of the informal sector in the SWM. Waste pickers and recycling shops should be involved in order to increase the recycling rate of the city. However, the inclusion of these actors is challenging in the world, and specific studies and projects should be implemented for understanding how it could be included in the formal SC system.

**Remarks**

The research was implemented thanks to the international cooperation network built during the years. The University supported the whole process of international cooperation, finding new partners and providing management plans and new tools. Therefore, the cooperation among foreign Universities, NGOs and the local government is potential for finding funds delivered specifically to projects for the international cooperation with appropriate researches and technical knowledge. In particular, the actions should be focused on training, in order to support the CE in the context of La Paz, distinguish two cases:

a) basic training for the population, evaluating how the environmental awareness is developed, which is the basis of a correct management of the MSW by the citizen;

b) high level training for local engineers who can also work in advance on SWM problems (to avoid cases like the collapse of the Alpacoma landfill).

In the second case, a development plan should be defined, presumably based on Bolivian doctoral students, in order to constitute a group of experts that can be activated when needed, in support of the authorities. The Ph.D. research developed in La Paz demonstrate that the international relations opened by the universities are key for supporting local authorities in introducing actions for boosting the CE and innovative SWM systems. It should be underlined that Bolivian Ph.D. students should be also a resource to be valued in order to provide sustainability to these actions.

In conclusions, this experience in environmental sciences and engineering allows understanding the main social, environmental, technical and economical issues for introducing new approaches for fostering sustainable development in low-middle income countries. Efforts should be spent globally in order to support these countries since the clock is ticking, and the environmental pollution is constantly increasing, reducing the opportunities to invert the trend of global warming and of the consume of non-renewable resources. We have now the opportunity to change, reducing the use of virgin materials and energy from fossil fuels, re-using what is used and recycling what is wasted. This Ph.D. provided support for introducing these principles, as example of good practices that can be implemented towards the circular economy in developing cities.