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Faculté des géosciences et de l'environnement

Municipal Solid Waste characterization, material flow analysis and boundary work to facilitate the integration of waste pickers in Tandil, Buenos Aires, Argentina

The challenges of transforming the waste management system of a city with transdisciplinary research

Thèse de doctorat

Présenté à la Faculté des géosciences et de l'environnement par

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Professeur Christian Kull

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PART III § FINAL REMARKS

List of Figures

List of acronyms

10YFP - 10-year Framework of Programmes
B2B - Business-to-Business
BRICS - Brazil, Russia, India, China, and South Africa
C&D - Construction and Demolition
CE - Circular Economy
CRM - Critical Raw Materials
CSS - Complementary Social Salary
CTEP – Confederación de Trabajadores de la Economía Popular [Confederation of the Popular Economy Workers]
DC - Developing Countries
DE - Domestic Extraction
DMC - Direct Material Consumption
DPO - Direct Processed Output
EMF - Ellen MacArthur Foundation
EPR - Extended Producer Responsibility
EU - European Union
EW-MFA - Economy-Wide Material Flow Accounting
GDP - Gross Domestic Product
GHG - Greenhouse Gases
GIRSU - Gestión Integral de los Residuos Sólidos Urbanos [ISWM]
HH - Household
HWGR - Household Waste Generation Rate
IE - Industrial Ecology
IRR - Iniciativa Regional para el Reciclaje Inclusivo [Regional Initiative for the Inclusive Recycling]
IRS - Informal Recycling Sector
ISWM - Integrated and Sustainable Waste Management
IWM - Integrated Waste Management
LAC - Latin-America and the Caribbean
LAE - Latin American Extension
MF - Material Footprint
MFA - Material Flow Analysis
MLP - Multi-level Perspective

MSW - Municipal Solid Waste

MSWM - Municipal Solid Waste Management

MTE - Movimiento de Trabajadores Excluidos [Movement of Excluded Workers]

NAS - Net Addition to Stock

NGO - Non-governmental organization

PAR - Participatory Action-Research

PCP - Persistent and Complex Problems

PDCA - Plan-Do-Check-Act

PE - Popular Economy

PFD - Process Flow Diagrams

RME - Raw Material Equivalents

SCP - Sustainable Consumption and Production

SDG - Sustainable Development Goals

SES - Socioeconomic Status

SHHW - Sanitary Household Waste

SMR - Social Metabolism Research

STS - Science and Technology Studies

SW - Solid Waste

Td - Transdisciplinarity

TM - Transition Management

TWM - Traditional (linear) Waste Management

UN - United Nations

UNICEN - Universidad Nacional del Centro de la Provincia de Buenos Aires

URM - University Reform Movement

WEEE - Waste from Electrical and Electronic Equipment

WM - Waste Management

WMS - Waste Management System

Acknowledgments

In October 2013, I went back to Argentina from Switzerland. My wife Pauline was 7 months pregnant. I was closing one of the most beautiful periods of my life in which, thanks to a Master scholarship of the University of Lausanne, I could attend splendid courses (and met Pauline in doing so) and spent a lot of time reading and learning about the past, present and improbable futures of our entangled relation with the environment.

The easy landing we had in Argentina would not have been possible without the help of my family, especially of my mother Silvia and my brother Nacho and his family. Their constant support and that of my friends, as well as the assiduous visits of Jacques and Claire, my in-laws, were very important in this process. I want to thank all of them and the rest of my family as well.

Pretty soon, a new and even more beautiful period of my life started, with the arriving of Leonora, our first daughter. Then, in 2015, when this work was still in its dawns, Emilia was born. Their presence gave me the hope I needed to achieve this thesis. To them and Pauline is dedicated this work.

Some months after my return to Tandil, I found an Assistant post in the Engineering School of the National University of the Centre of Buenos Aires Province (where I am today a Professor) and a vacancy in the Environmental Studies and Research Centre (CINEA) in the Humanities School of the same university. All along the period of this thesis, I worked in both places. I felt comfortable with this hybrid condition, which, I think, reflects very well my educational journey and is, in turn, reflected in this thesis. A big thanks to all my colleagues.

When in 2014 I contacted Suren Erkman, my Master thesis director, with the idea of starting a Ph.D., it was like a remake of our first contact in 2010, when I asked him to be my scholarship tutor in Switzerland. As in 2010, he trusted me and, this time, he also accepted to direct this thesis at the distance. I am therefore very grateful also with him, who accompanied this process from the very beginning.

Abstract

Municipal Solid Waste (MSW) management is an important challenge in developing countries, where the recovery of recyclable materials is often made in informal conditions by waste pickers. How to pass from a deficient waste management system to an improved one (and what does it means) and how to integrate waste pickers in the formal system are therefore crucial questions. This thesis was aimed at the enhancement of the waste management of Tandil, a city of the Buenos Aires province (Argentina), especially concerning the situation of local waste pickers. On the one hand, our approach combined a local transformation and action-research framework, the Latin American Extension, with transformational approaches used to solve societal persistent complex problems, mainly transdisciplinarity. On the other hand, we generated basic knowledge regarding the local waste management system. The thesis combines three published articles with several introductory chapters in which we justify the adopted approach and we describe the actions that supported and followed the generation of the articles' knowledge. In the **first article**, we worked with Argentinian researchers and students to apply a standardized methodology of waste characterization under budget constraints to obtain the generation rate per category of waste. We identified several specificities in our results related to the high loss of mass during the picking analysis. We associated it with a typical habit of our region, i.e. the consumption of yerba mate, a supposition that needs further research. In the **second article**, we used the information of waste generation in combination with other primary and secondary sources with two main purposes: 1) to calculate indicators related to formal and informal waste recovery; 2) to evaluate how the system was functioning regarding the drivers of integrated sustainable waste management (ISWM). Our results showed that, as in many cities of developing countries, informal recovery is higher than formal recovery. Moreover, we analysed the inadequacy of current local recovery strategies regarding the legislation in force. With this information and through different interventions along several years, we supported the formation of the local waste pickers cooperative. In our **last article**, we analysed how the integration of waste pickers evolved in Tandil, regarding the local situation and some important changes occurred at the national level. Along our work, we tried to involve the local government in co-creation dynamics to co-construct a vision of the future waste management system. However, we never achieved this objective.

Preface

I write these words in a particular moment of the recent history, which may be called in the future "the coronavirus (or COVID-19) world crisis": a new virus outbreak originated in China in late 2019 became pandemic in early 2020, wavering the world economy, challenging existing power orders and, at the same time, opening opportunities for (radical?) change.

Likewise, this thesis was developed during a very singular moment of the recent Argentinean history. Between 2016 and 2019, the country experienced one of the worst economic and social crises of the last 40 years (that is, since the end of the last military dictatorship). The combination of neoliberal policies based on the opening of economic barriers to the import of goods and the export of raw materials, together with financial measures based on the orthodox economic doctrine such as the increasing of the benchmark interest bank rate up to 60-70% (intended to reduce inflation) and the free movement of foreign capitals, followed by a short-term and high-rate debt uptake to balance capital flight, resulted in budget cuts, the increase of poverty and unemployment, a 26% fall of citizen revenue's purchase power, a 300% inflation rate, an abrupt fall of the economic activity and a quasi-default situation only comparable with our 2001 economic crash.

All aspects of daily life were affected by these facts. For the social sectors already under the poverty line and marginal before the beginning of the crisis, the situation was (and is) exceptionally critical. The COVID-19 pandemic was like this unexpected wave in the sea that arrives when you thought the worst had ended.

Researching in a context of personal worries and general social injustice is not straightforward. However, sad as it may sound, we got used to it: high inequalities, structural poverty and repeated crises are persistent features of most countries in the Latin American and the Caribbean (LAC) region. It does not mean that we simply accept this reality, though. A strand of researchers in LAC have historically searched, first, for an understanding of the deep causes of this poverty trap and for envisioning more desirable futures; second, for a transformation of this reality through *praxis*. With this aim in mind, several schools of thought as the *Pensamiento Crítico Latinoamericano* (Latin American Critical Thought; LACT) and action-research approaches as the *Investigación Militante* (Militant Research; MR) developed between the ’50 and the ’80. Researchers of these movements were socially and politically engaged; they also promoted changes in universities functions and structures, following the legacy of the Cordoba Reform and fostering the Latin American University Extension (LAUE) movement[1]. Therefore, these temporal and spatially bounded approaches, shaped the current LAC universities institutional configurations and are present (at least in the National University of the Centre of the Buenos Aires Province) in the form of programs and calls for projects, among others.

At the same time, and in the context of sustainability research, the recent emergence of a *transformative science* field, aimed to initiate and/or catalyse societal transformations, shares several aspects with the mentioned LAC approaches. First, a normative position: depending on the definition of sustainability adopted, we can think that LACT, MR, and LAUE are all focused on achieving of sustainability. Second, the incentive of integrating different types of knowledge, which implies that some boundaries need to be partially erased. Finally, this challenge calls for the use of adequate methods and tools.

These two linked knowledge and epistemological approaches are part of this thesis. On the basis of my background in engineering and environmental sciences, the original subject of this thesis was the use of the urban metabolism approach in Tandil, focused on the industrial park of the city. I would use Material Flow Analysis and methods of the sustainability transitions approach. The project was welcome by the park authorities, and everything seemed to be on track. However, when my fieldwork was about to begin, in 2016, the entry to the park was blocked by employees that have been made redundant. Two weeks later, when the entrance to the park was released, the park authorities told me their priorities had changed. It was the beginning of a long economic crisis.

Some months later, I had the opportunity to support the work and the self-organisation of the local waste pickers, so I decided to point my research in this direction. I realised that it was natural for me to follow the LAUE tradition of political and social engagement. Moreover, I saw the opportunity of linking my research activity to a personal motivation of helping a vulnerable sector of the society that was heavily affected by political decisions and the economic situation.

[1] See Ch. 7.

However, much of the work related to the overall objective of this thesis, that is, to improve the waste management of my hometown with a special concern about the waste pickers' situation, is not reflected in this document. This work took the form of several mini-projects, a lot of meetings, press, radio and TV interventions, the drafting of several regulation proposals, blog articles, and press releases, among others. I cannot say that this was not part of the thesis, even when it cannot be placed in the "scientific" realm. As in the case of the integration of different types of knowledge, when we are engaged with a subject in this way, several boundaries are partially erased: free-time and research activities, working and personal relations, and so on.

The decision of doing this thesis through scientific articles is also related to this point: I wanted to make clear that I was (also) doing "good" science. I was concerned with the production of high-quality information to support decision making. Maybe naively, I thought it could also legitimize my work concerning the local government, facilitating the planned and needed phases of co-production of knowledge. However, it was not the case. All my attempts to involve the municipal stakeholders in work dynamics aimed to co-create an assessment and a vision for the waste management system were futile. This thesis is, therefore, incomplete in this sense.

Yet, I believe the knowledge generated is not worthless. Indeed, it has fuelled a process that has not ended. In the context of my academic activities as a professor, for 5 years now, I taught the course "Circular economy: scope, limits and tools" (called "Introduction to the industrial ecology" before). The exchange with my students, their questions, my motivation to improve my classes, were also part of this long research process and it will continue. Also, I have supervised several undergraduate theses and internships related to waste issues, as the estimation of the costs of the local waste management system, the first life-cycle assessment of the plastic recycling circuit of Tandil for 2017, an assessment of the WEEE management of the City (in process) and a concluded work regarding the waste management of the University Campus from an inclusive recycling perspective[2]. Even if 2020 was a very difficult year, I proposed and coordinated the first Open Lab in Inclusive Recycling of my hometown[3], in which we made an open call of ideas to improve the work of waste pickers. With a team of volunteers, I am now working on the design of an App to improve the (reverse) logistics

[2] See Ch. 2

[3] See https://cuic.unicen.edu.ar/2020/12/pesentacion-de-resultados-del-primer-laboratorio-ciudadano-sobre-reciclaje-inclusivo/ (in Spanish, accessed 08/01/2021)

of waste pickers. Also, in 2021-2022 I will direct a project related to the use of rEPS in the construction of wet panels to be used in social housing.

Even if these activities are out of the scope of this thesis, everything was and is made with the same purpose and the same engagement.

Structure of the Thesis

This thesis consists in three articles which were published in 2020 in three different scientific journals: 1) Resources, Conservation and Recycling (Q1, Impact factor = 8,068); 2) Journal of Environmental Management (Q1, Impact factor = 5,647), and; 3) Waste Management & Research (Q2, Impact factor = 1,114). However, the articles alone are not enough to understand why and how we did our work. Indeed, they correspond to only 3 out of the 12 Chapters of the thesis.

The thesis is organized in three parts. Part one, the Introduction, comprises 6 Chapters and is devoted to the definition of our problem statement, the research questions, and the methodology.

Chapter 1 is intended to contextualize Municipal Solid Waste (MSW) in global materials flows, and MSW management in other strategies of resources management. We also explore if current approaches of the circular economy are adequate for developing countries.

Chapter 2 presents two different approaches to waste management, the Traditional linear (TWM) and the Integrated Sustainable (ISWM). Also, and based on the analysis made in Chapter 1, we sketch what for us is a better conceptualization of the CE for developing countries. The Chapter concludes with a basic insight: knowing what the MSW should be (ISWM) it is not enough; we need to know how to make a transition from one system to another.

Chapter 3 is therefore devoted to present selected research methodologies aimed at addressing persistent complex problems (PCP). These methodologies are interdisciplinarity, post-normal science, and transdisciplinarity. Indeed, we argue that waste management is a PCP, at least in many developing countries.

In Chapters 4 and 5, we focus on our study case. We give a general description of Argentina before presenting its environmental legal structure. Then, we focus on waste management regulations, first at the national level and then with more details for the

Buenos Aires province. We close Chapter 4 with reflections regarding the failure of the waste legislation. In Chapter 5 we introduce the territory of this thesis, the city of Tandil. After a geographical, socio-economical, and demographical description of the city, we present the baseline situation of Tandil waste management at the beginning of the thesis.

In Chapter 6 we use insights gained mainly in Chapters 2-5 to define the research questions and the methodology of the thesis, which are based on the transdisciplinary approach.

Part two comprises five chapters, three of which are the scientific articles of the thesis.

In Chapter 7 we present what for us is an institutionalized approach of transdisciplinarity in Latin America, the University Extension. We review the history of this field, as well as its recent evolution, mainly in Argentina

In Chapter 8 we explain how, in the context of a university extension project, we worked to improve the recognition of the waste pickers' work. Also, we explain how we managed to be part of a boundary organization formed to improve the city waste management. Finally, we give the background and some details of the scientific articles of the thesis.

Chapters 9-11 are the published articles.

The thesis closes with the Final remarks (Chapter 12). We recap the milestones of the work performed and analyse, first, how the reviewed conceptual approaches were integrated in the thesis and then, what are the future research and action perspectives.

Tandil, 22 January 2021.

PART I

§ Introduction

1

Closing material cycles to revert The Great Acceleration?

Since the end of World War II, the extraction of raw materials, GDP, population, and other global variables have increased exponentially, mostly driven by the consumption demands of developed countries (Steffen et al., 2015) and, in recent decades, by the growth of the BRICS, mainly China (Schandl et al., 2018). This period is currently referred to as The Great Acceleration (Steffen et al., 2015, 2007) and is considered the beginning of a new geological era called the Anthropocene[4] (see Figure 1).

As Monsaingeon (2017) states, all possibilities explored for dating the beginning of the Anthropocene relates to waste[5] generated by humanity, either diffusely (plastics, CO_2, new substances) or through specific events (nuclear tests). This stands on the fact that, as other impacts related to the Great Acceleration (see Steffen et al. 2015, Figure 3), waste generation has grown exponentially. Therefore, waste is perceived, first, as one of the biggest problems of our society, and second, as one of the great opportunities to reduce the impact of our activities on the environment[6].

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[4] The Anthropocene marks the end of the Holocene and the beginning of the homo sapiens as a geological force, given the global impact of human activity on ecosystems. The precise date of the beginning of this new era is currently under debate (Waters et al., 2018; Zalasiewicz et al., 2015), for which it is necessary to obtain some adequate record (stratigraphic markers). The term Anthropocene has been largely criticized. For a summary see Mathews (2020).

[5] The term waste refers, according to the Oxford Dictionary, to materials that are no longer needed and thrown away. However, the usefulness of a material can be null for a person but not for another, which shows that there is a certain subjectivity in the definition of waste.

[6] Importantly, while the extent -and the improvement potential- of the waste issue may seem overwhelming, it should be recognised that generating waste is a fundamental consequence of life-sustaining actions (metabolism). "An organism that does not generate waste, says Monsaingeon (2017, p. 24), is a dead organism." We will generate waste while being alive. That is why waste management is considered as a basic human need (Jolly, 1976) or as a fundamental right (UNEP and ISWA, 2015). Therefore, it is not the fact of generating waste what distinguishes us as a society or civilization, but how (much) we generate, how it is composed and what we do with it.

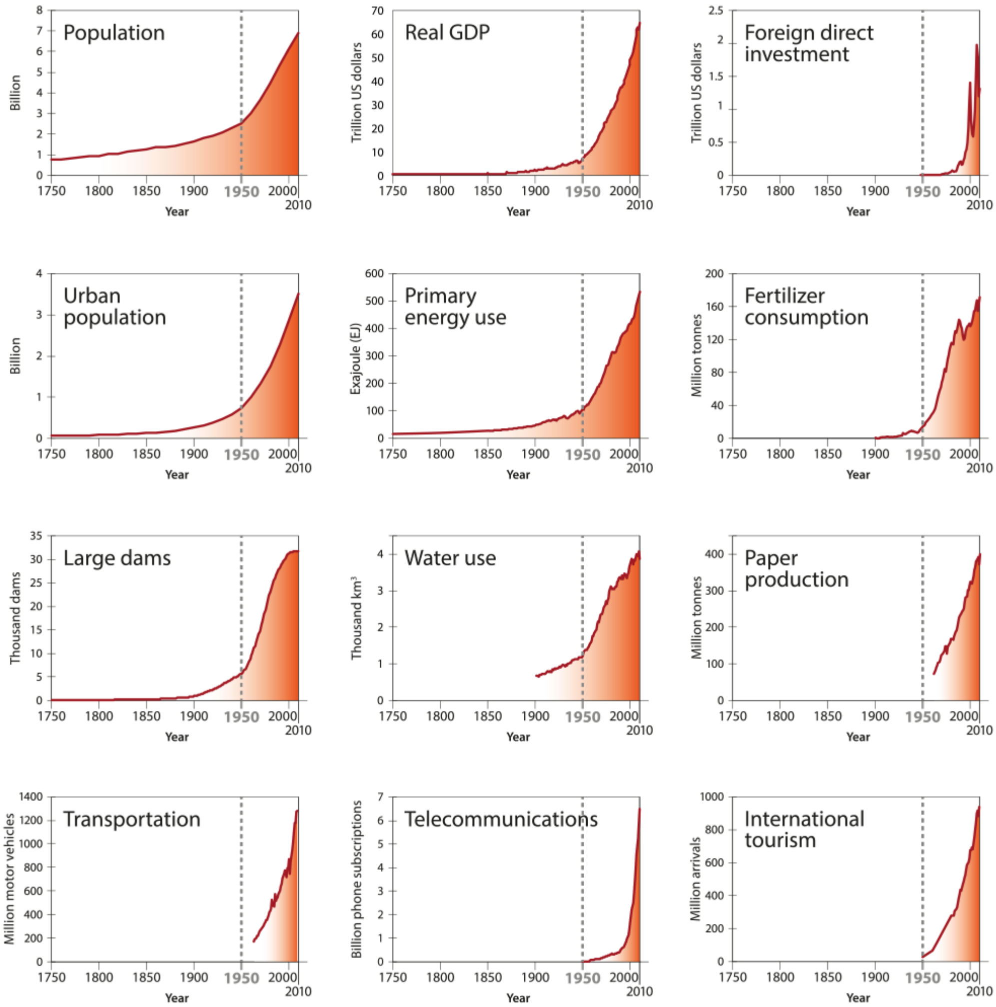

Figure 1: Trends in diverse global indicators. As of 1950, the Great Acceleration begins. Source: Steffen et al. (2015)

In recent years, a narrative has gained popularity which associates these trends with the existence of a “linear economy” and proposes a “new paradigm” of resource management called “the circular economy” (CE) to reverse this course (Calisto Friant et al., 2020; EMF, 2015; Geissdoerfer et al., 2017; Ghisellini et al., 2016; Roy, 2021).

Since this thesis is focused on the waste management field, which is often conceptualized as part of the circular economy (sometimes also as a synonym), we will start this Introduction by a brief development of the CE and its limitations, which will help us to put the work we present here in context. Our aim is not to perform an exhaustive literature review, but to identify key aspects that can help to critically analyse global material flows, including Municipal Solid Waste (MSW)[7]. Since our work is based on Argentina, we will also analyse the suitability of CE models to

[7] See its definition in the next Chapter.

developing countries, with the aim of setting the grounds of a better CE model (see next Chapter).

In section 1.1 we will explore the antecedents of the CE, focusing on the three fields which, in our opinion, summarize the main proposals moved forward in CE narratives: Sustainable Consumption and Production, Industrial Ecology and Waste Management[8]. Then, we will briefly analyse what we consider the two main current approaches of the CE, the model of the Ellen Mac Arthur Foundation and the European Union CE Plan, and their appropriateness for developing countries.

In section 1.2, we will succinctly present the methodology of Economy-Wide Material Flow Analysis, along with some recent works which help to put the CE narrative into perspective, showing its limits. Finally, we will analyse the limits of MSW as a source of materials "to close the material cycle".

1.1 A brief development of Circular Economy approaches

1.1.1 Antecedents of the Circular Economy

The idea of recirculating materials by revaluing waste is not new. In fact, it has been a common practice until recently. In Europe, between the eleventh and eighteenth centuries, many people recovered rags, mostly linen and cotton, and sold them to make paper (UN 2018). In London, between the late eighteenth and mid-nineteenth centuries, the communes hired people to sweep the streets, remove the waste from households and transport it to separation centres (dust-yards). Then, they sold it in a market for recovered materials. Most of this waste was coal ash and firewood, used to make bricks, and soil and excreta, used as a fertilizer. Thus, 100% of this waste was recovered (Velis et al., 2009, p. 253).

Morigeon (2017) gives numerous examples of how, in the nineteenth century, urban wastes - mostly organic - were used systematically as inputs of the industrial processes or as fertilizers for agriculture. Moreover, he affirms that the concept of "garbage" did not exist at that time and that the waste condition was considered a transitory state of matter. *Salpêtre*, i.e. potassium nitrate, which was obtained in places where organic waste was disposed, was the main raw material for black gunpowder, a fundamental input for cities. At the same time, the effluents of excrements were stored and exploited industrially to manufacture *poudrette*, a fertilizer obtained from its drying and

[8] This concept is deepened in the next chapter.

pulverization (Esculier and Barles, 2019). At the end of the 1800s, waste picking was a subsistence activity for many people in France (Cornière and Fisseux, 2012).

Figure 2: Left: Le chiffonniers de Paris - Le journal illustré, dessin d'après nature, de Henri Meyer (1884) ; Right : Collection of night soil in Paris (1820). Sources: Cornière et Fisseux(2012) and Esculier and Barles (2019)

We might think that the same was impossible in 20th century. A documentary film called "The Zone", shot in Paris in 1928 by Georges Lacombe, shows the contrary. It describes the life of the waste pickers ("chiffoniers") who lived on the outskirts of Paris. The film also shows how the French capital managed of materials. Waste pickers recovered rags, bones, glass, and other materials early in the morning. The collection service then collected waste and took it to an incineration plant, where, after a new segregation made in-situ by waste pickers and a sieving process to recover organic matter for further use as fertilizer, metals were recovered, waste was burned to produce electricity, and ash was then conducted to a brick factory.

Figure 3: Screen captures from the film "La Zone" de Georges Lacombe. The film is available at: [*http://www.mheu.org/fr/chiffonniers/zone.htm*](http://www.mheu.org/fr/chiffonniers/zone.htm) *[accessed 19.01.2020]*

The mass consumption of the second half of 20th century, based on the transition to a fossil energy system in the current developed countries (Schaffartzik and Fischer-Kowalski, 2018), along with the availability of synthetized nitrogen and the exploitation of phosphate rock and other important changes, transformed that world. The hygienist movement also influenced the conception of waste, which was seen as a source of diseases (Morigeon, 2017).

However, only some decades later, the concern about the use of resources and its environmental impacts started to be addressed in different (and somewhat overlapping) fields, corresponding to different spheres of action and levels.

1.1.2 Sustainable Consumption and Production at the international and institutional level

In the institutional sphere and at the international level, the United Nations (UN) Organisation, through its conferences and agreements, nested the development of an environmental diplomacy at the global level in which resource and waste issues have been largely addressed (Chasek, 2020). Already in 1949, some years after its creation, the UN held the International Scientific Conference on the Conservation and Use of Resources (Jackson, 2014). Then, from the 1972 Conference on the Human Environment in Stockholm to the Sustainable Development Goals (SDG) of the 2030 Urban Agenda, the development of a field called Sustainable Production and Consumption took form at this level. The Agenda 21, signed in 1992 at the Conference on Environment and Development (UNCED) held in Rio de Janeiro, stated that "the major cause for the continued deterioration of the global environment is the unsustainable pattern of consumption and production, particularly in industrialized countries…" (United Nations, 1992; paragraph 4.2). The Agenda was mainly focused on the demand-side of the production and consumption system, stressing the role of consumers (the related chapter is called "Changing consumption patterns"), the unsustainable ("wasteful") lifestyles of rich segments, and the shortages in those of the poor due to an imbalanced use of resources and its impacts. It called for a sustainable consumption which will guarantee the fulfilment of the basic needs of humanity and for an efficient production system. This conception was reaffirmed in the Oslo Symposium on Sustainable Consumption of 1994, whose definition of sustainable consumption also included the life-cycle approach.

In the 2002's Earth Summit of Johannesburg, however, the focus was on "changing consumption and production patterns", and the references to the "basic needs" and the "sustainable lifestyles" were removed, while that of "decoupling" economic growth from environmental impacts was included. Importantly, the Plan of Implementation of the Summit promoted "the development of a 10-year framework of programmes in support of regional and national initiatives to accelerate the shift towards sustainable consumption and production [SCP]" (UN, 2002, p. 13). In the years that followed the conference, a global multi-stakeholder process to support the implementation of SCP and to develop a Global Framework for Action on SCP called the Marrakesh Process worked internationally on this objective.

The SCP definition developed for the 10-year Framework of Programmes (10YFP) was finally focused on resource efficiency and decoupling and kept the life-cycle approach (UNEP, 2010). The 10YFP for SCP was adopted at Rio+20 in 2012, and then reaffirmed in the SDG 12. It is now anchored in the One Planet Network[9].

The main strategies promoted in the field of SCP are focused on public policies to promote: Resource Efficiency and Cleaner Production, Sustainable Public Purchasing, Consumer information (eco-labelling and certification), and Sustainable Tourism (Akenji et al., 2015).

The target 12.1 of the Sustainable Development Goal number 12 "[to] Ensure sustainable consumption and production patterns", proposes to "implement the 10-year framework of programmes on sustainable consumption and production, all countries taking action, with developed countries taking the lead, and taking into account the development and capabilities of developing countries". By 2017, 71 countries (including many developing countries) had a SCP Plan (see Figure 4), while in 2019, 79 countries and the European Union "reported on at least one national policy instrument that contributed to sustainable consumption and production" (UN, 2020).

[9] www.oneplanetnetwork.org [accessed 15.01.2020].

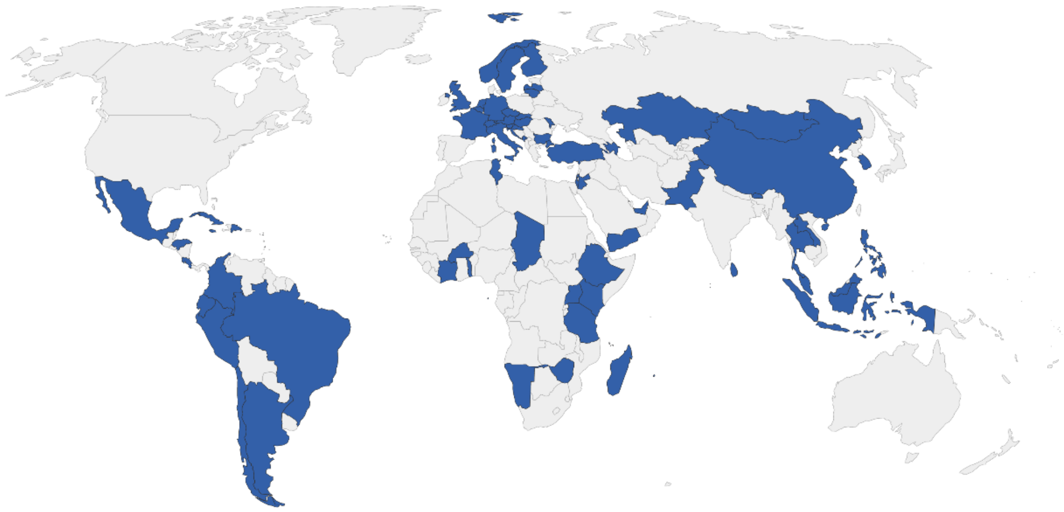

Figure 4: In blue, countries with a SCP national action Plan. Source: Our World in Data

1.1.3 Industrial ecology as the central component of the CE

The field of industrial ecology (IE) is recognized as one of the main roots of the circular economy (Bruel et al., 2018; Ghisellini et al., 2016; Reike et al., 2018).

Its conceptual origins were already present in the intellectual exchanges that followed the 1972 UN Stockholm conference, during the creation of the United Nations Environmental Program (UNEP), in the United Nations Industrial Development Organization (UNIDO), and the United Nations Economic Commission for Europe (ECE), but its consolidation took place mainly in academic and business circles in the 1990s (Erkman, 1997). An article by two industrial engineers[10] working for General Motors, Robert A. Frosh and Nicholas Gallopoulos, in 1989, is often signalled as the actual departing point of the field (Gallopoulos and Frosch, 1989).

Despite the existence of many different definitions of the IE, according to Erkman (1997, p. 1-2), its perspective can be summarized by:

> *1. It is a systemic, comprehensive, integrated view of all the components of the industrial economy and their relations with the biosphere.*
> *2. It emphasizes the biophysical substratum of human activities, i.e. the complex patterns of material flows within and outside the industrial system, in contrast with current approaches which mostly*

[10] Scholz (2011a) identify both industrial and environmental engineering as forerunners of industrial ecology.

consider the economy in terms of abstract monetary units, or alternatively energy flows.

3. It considers technological dynamics, i.e. the long-term evolution (technological trajectories) of clusters of key technologies as a crucial (but not exclusive) element for the transition from the actual unsustainable industrial system to a viable industrial ecosystem.

Scholz (2011a) assigns interdisciplinary roots to industrial ecology. Moreover, about its methods, Scholz atates that "We distinguish between methods for: (i) describing/representing industrial ecological systems; (ii) evaluating "industrial systems or processes;" and (iii) transforming these systems" (p. 313). The main analytical tools of IE are Material Flow Analysis (Brunner and Rechberger, 2017) and life-cycle assessment (Ayres and Ayres, 2002).

1.1.3.1 The main components of the IE

According to Erkman (2004) the main drivers of IE are: (i) to value waste as a resource; (ii) to loop material cycles and minimize dissipative emissions; (iii) to dematerialize products and economic activities; and, (iv) to decarbonize energy production. Different strategies were developed in the field, some of which already existed. Figure 5 summarizes the main strategies of the IE at different levels.

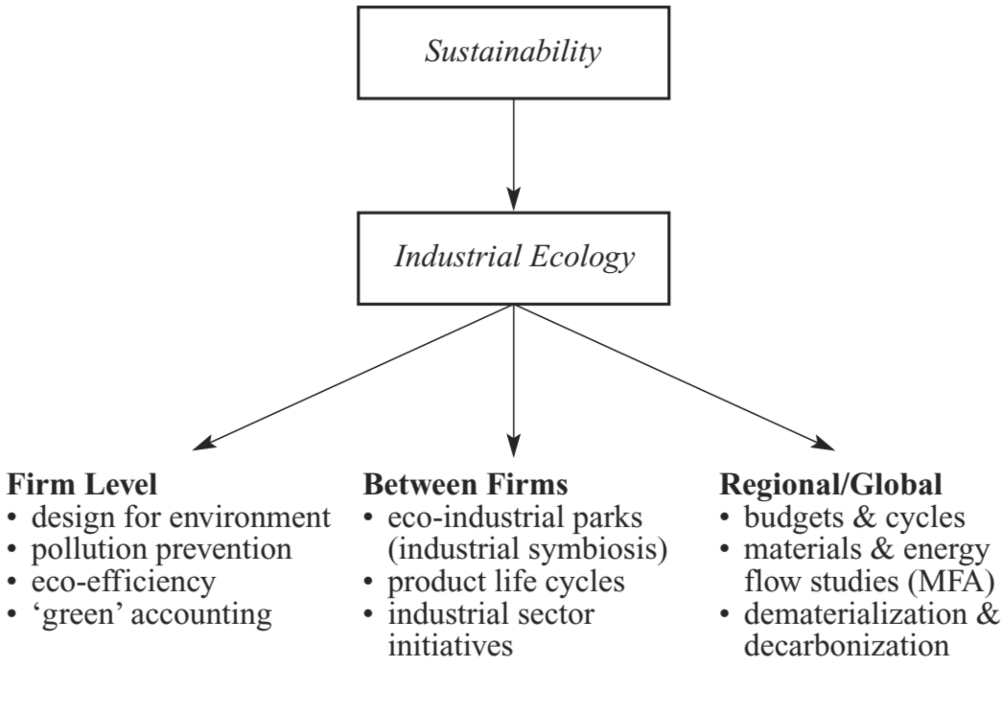

Figure 5: Main strategies of the IE at different levels. Source: (Ayres and Ayres, 2002, p. 10)

The most operationalized concepts of IE are industrial symbiosis and eco-industrial parks (Clift and Druckman, 2016). Under the IE premise that we can consider the urban-industrial system as a particular case of ecosystem (Hardy and Graedel, 2002), industrial symbiosis is the actions that allow industrial or urban by-products to become inputs of another industrial process (Chertow, 2000; Desrochers, 2001; Van Berkel et al., 2009). Eco-industrial parks or Eco-innovation parks, even if they were associated with industrial symbiosis (see for example Figure 5), are now defined more generally as "an earmarked area for industrial use at a suitable site that ensures sustainability through the integration of social, economic, and environmental quality aspects into its siting, planning, operations, management and decommissioning" (UNIDO, 2017, p. 5).

Another key-concept of IE is eco-design, which applies to both products and processes and seeks to minimize their impacts throughout all the phases of their life cycle (Ehrenfeld, 1997). It refers to a design that satisfies the consumer but at the same time seeks to minimize the use of hazardous or difficult-to-recover materials and that facilitates the reuse, repair, remanufacturing or recycling of products once their life cycles end (Bourg and Erkman, 2003).

The functional or service economy, which focuses on replacing consumption with use and therefore prioritizing services to products (Erkman, 1997; Stahel, 2019, 1981), is another component of the IE field. It is a business strategy that discourages the planned obsolescence because, instead of selling a product, the companies sell a service. Therefore, they are interested in that machines are easy to maintain and repair and have the longest possible duration. One of the best-known examples is Xerox, the company that previously sold its photocopiers and now sells "copies", taking care of the maintenance and updating and reuse / recycling of machinery parts (ibidem).

Graedel and Lifset (2016, p. 5) claim that even if "IE is today regarded as an academic specialty (...) it continues to rest on the foundation developed and practiced by industry and, to some extent, by governments". Shenoy (2016) states that EI has been applied in developing countries, mainly through eco-industrial parks and cleaner production initiatives, related to the work of UNIDO.

1.1.4 Waste management driver's evolution and the waste hierarchy

Finally, the field of MSW[11] Management also followed its own evolution to address the concerns about resources management.

In the span of a few decades, the guiding principles of and the expectations about waste management changed (see Figure 6). To the preservation of public health original driver, the aim to reduce, at the same time, the damages generated on the physical environment was added, which gave rise to sanitary landfills, incinerator filters, and other methods of safe final disposal. In recent years, the vision of "waste as resources" that need to be managed regained place in waste management agendas[12].

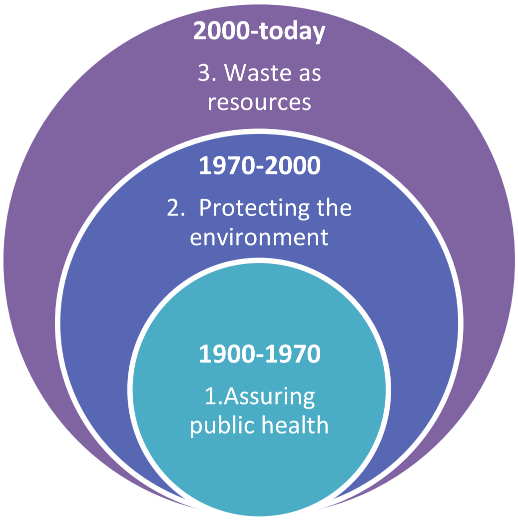

Figure 6: Evolution of drivers in waste management. Source: Based on Wilson (2007)

It was well before the '2000s, however, that one of the best-known resource management principles included in waste management frameworks was formulated:

[11] There are many possible classifications of waste. First, we can classify waste regarding its state: liquid, solid, or gas. Commonly, in the case of gases or liquids, we use the term effluent instead of waste. Here, following Tchobanoglous et al. (1982, p. 6) we will define solid waste as "all wastes steaming from human and animal activities that are normally solid and that are disposed of as useless or unwanted". It should be noted that solid waste may be responsible for the generation of gaseous or liquid effluents, which justifies the special attention they receive. Municipal Solid Waste is, subsequently, solid waste generated in urbanized areas (see next Chapter for a detailed description).

[12] Many authors point out that resources recovery is a driver that precedes and follows the other drivers (see for example Monsaingeon, 2017; Velis et al., 2012; Wilson, 2007). Therefore, it is a return to practices that historically were carried out in the cities, especially in the case of nutrients recovery (food scraps, sewage, etc.) for agriculture. On the other hand, certain authors suggest Climate Change as an emerging driver of WM (Scheinberg et al. 2010).

the waste hierarchy. This hierarchy has been part of the European legislation since 1975,[13] and establishes a guide of priorities for public policies in this area.

The waste hierarchy is based on the principle: "the best waste is no waste at all". If waste cannot be avoided, then the objective is to reduce its generation and/or to reduce dangerous or difficult-to-treat components. Once the product or material enters the economy, what is sought is that it provides a service as long as possible there, through repairs or new uses. Then, we seek to recycle, if possible, preserving the material's properties or using it in a greater value-added product (upcycling), avoiding quality losses (downcycling). Finally, if the waste cannot be avoided, energy recovery strategies are prioritized to its final disposal in a sanitary landfill or to incineration without energy recovery.

The first three options of the waste hierarchy, by definition, do not involve waste itself, since they are conceived to avoid the upstream embodied materials flows of waste. The fourth and fifth are intended to recover value and energy embedded in waste. These are the reasons why waste management overlaps with (first three options of the waste hierarchy) or is absorbed (last three) by what we call today the CE.

In the next sections, we will briefly present two different approaches of the CE, with the objective of exploring the role of waste management on them. Then, we will analyse how they fit into the situation of developing or low and middle-income countries.

1.1.5 The Ellen Mac Arthur Foundation approach

Many different definitions of the CE can be found (Kirchherr et al., 2017). One of the most widespread definitions is:

> *A circular economy is one that is regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological*

[13] Framework Directive on Waste (1975/442/EEC), which has been updated in the Directive 2008/98/EC with quantified objectives and, more recently, in the Circular Economy Package.

cycles. This new economic model seeks to ultimately decouple global economic development from finite resource consumption.

(EMF, 2015, p. 2)

The approach of the Ellen Mac Arthur Foundation is summarized in the butterfly diagram reproduced in Figure 7.

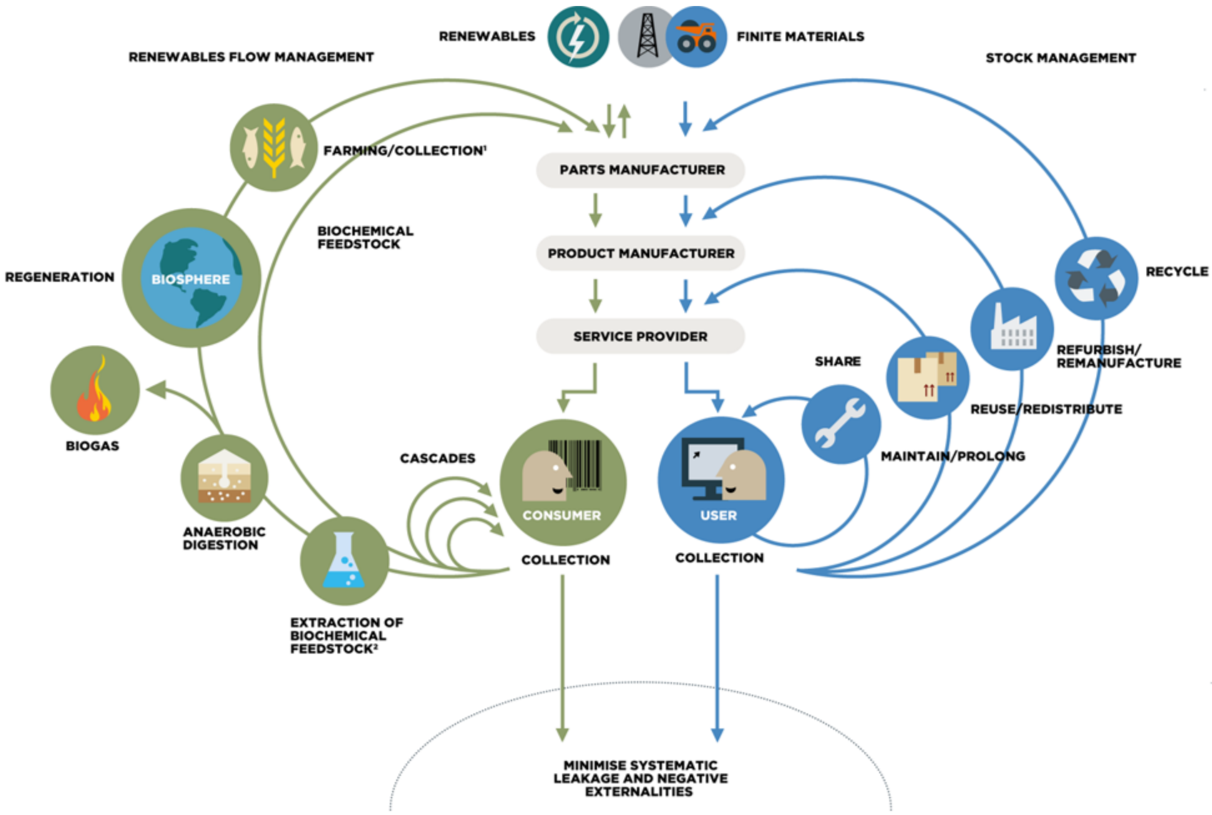

Figure 7: The butterfly diagram which summarizes the approach of the Ellen MacArthur Foundation. Source: (EMF, 2020)

The framework is characterized by the two cycles, the technical (right), which corresponds to products based on finite resources, and the biological (left), which is based on renewable resources flows. In the technical cycle products are restored and in the biological cycle, resources are regenerated.

Morseletto (2020) shows that restoration and regeneration are used differently in CE literature. Moreover, he states that it is difficult to find clear examples of what regeneration of the biological cycle means. On the contrary, from the EMF diagram we see that restoration of products refers to what, since several decades, has been part of other fields as the Product Recovery Management (Stindt et al., 2017; Thierry et al.,

1995) or reverse logistics (Dekker, 2010). It is focused on the retention or recovery of the residual value of products by companies and stands on a horizontal business to business (B2B) perspective.

Surprisingly, waste management is not part of the EMF CE framework. No waste is generated along the supply chain, because "[i]n a circular economy, waste does not exist" (EMF 2015, p.11).

1.1.6 The European Union approach

In 2015, the European Union launched an ambitious Action Plan for the Circular Economy (European Commission, 2015)[14]. The plan has four main components, which are Production, Consumption, and Waste Management for Secondary Raw Materials supply.

Regarding waste management, the 2015 Action Plan states that it "plays a central role in the circular economy". Two main aspects are highlighted: 1) its general role in the implementation of the waste hierarchy, and; 2) its specific role in the recovery of secondary raw materials (SRMs).

This second factor is advanced as one of the main drivers of the CE strategy in the EU. Since 2008, the EU deepened in the identification of Critical Raw Materials (CRM). CRM are defined as those raw materials with a high supply-risk and a high economic importance (European Commission, 2018). Periodically, the EU updates a list of CRM. The last 2020 list contains 30 CRM, while the assessment contained 14 materials in 2011, 20 materials in 2014, and 27 materials in 2017 (European Commission, 2020a). These materials are, in much cases, key inputs for the production of new technologies (see Figure 8).

[14] Individual policies at the country level already existed. Reike et al. (2018) mention the examples of Denmark, Germany, the Netherlands, and the UK.

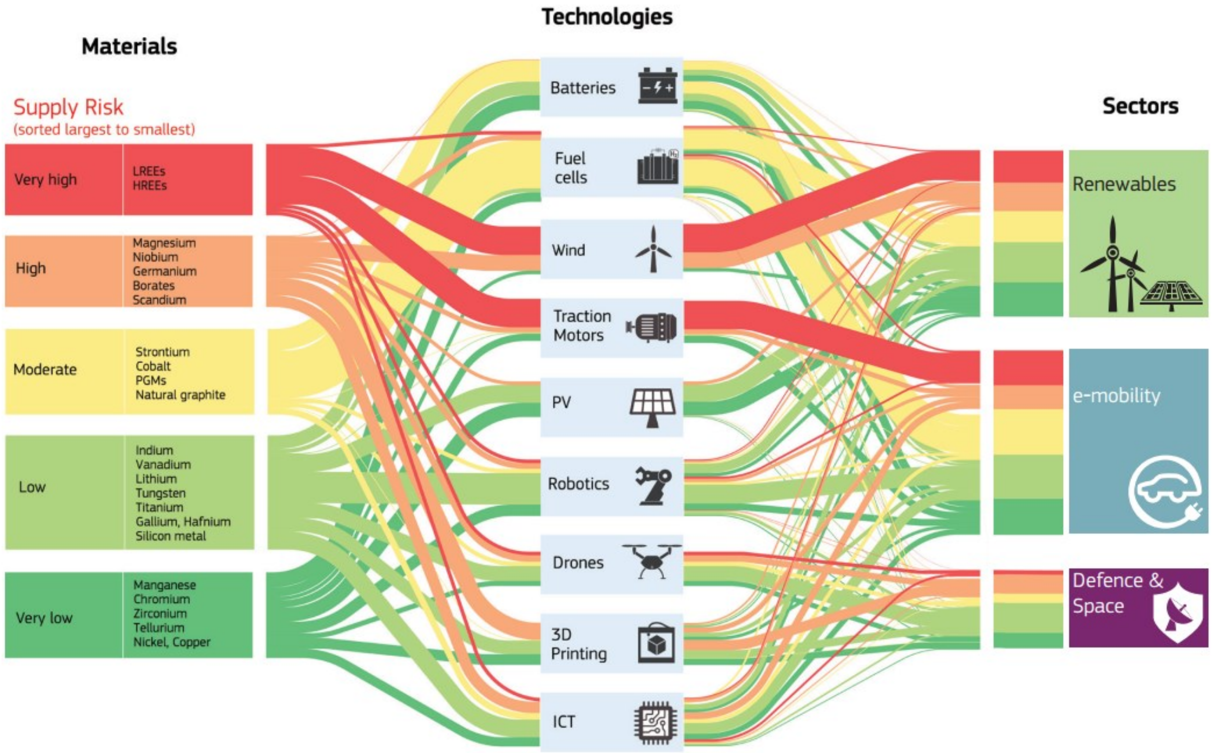

Figure 8: Flows of raw materials with indication of their current supply risks considering nine selected technologies and three key sectors of the EU (based on 25 selected raw materials). Source: European Commission (2020b)

The New Plan for the Circular Economy of 2017 is associated to the European Green Deal and is considered an indispensable part of the new EU industrial strategy as a provider of jobs and lower cost materials. It includes initiatives "along the entire life cycle of products", although is focused on specific sectors: "batteries and vehicles; packaging; plastics; textiles; construction and buildings; food; water and nutrients" (European Commission, 2020c).

Because of the EU nature, both the 2015 and the 2017 CE strategies are part of a top-down approach based on regulations and research innovation (Ferronato et al., 2019).

1.1.7 The CE in developing countries

The CE models of the EMF and the EU are hardly extensible to developing countries. In the first case, what is called the restoration cycle, is already part of the daily practices of most low and middle-income countries. Secondary markets in which the residual value of products is recovered have always existed; they are related to the consumers' impossibility of buying new products when the old ones break down, and to the niche opportunity seen by repair or resell service providers. In this context therefore, the EMF CE model makes sense only to companies which sell their products in these countries, which want to recover the end-of-life or residual value of their products themselves.

The second case, the EU CE model, fits the socioeconomic, infrastructure, and institutional features of the EU region. In developing countries, recycling chains are still poorly developed (Ferronato et al. 2019). A regulatory and ambitious top-down approach like the EU CE model would probably be a dead letter if it is not supported by economic and knowledge resources.

Despite all this, the CE discourse is not absent from political and academic sectors of developing countries, even if scientific research is significantly biased to developed economies (Kirchherr and van Santen, 2019). However, due to the challenge that waste represents for most countries of the Global South (existence of open dumps, low recycling rates, health and environmental risks), CE is often viewed as improved waste management (Ghisellini et al., 2016; Gutberlet et al., 2017; Ilić and Nikolić, 2016; Kurniawan et al., 2021; Scheel et al., 2020).

On the other hand, actors that are not present in developed regions operate in developing countries. In many low and middle-income countries, recycling is possible thanks to the work of waste pickers (Scheinberg et al., 2010b). Waste pickers are often people who have found a mode of subsistence[15] in the recovery and resale of recycling materials. Most of the waste pickers create their manual- or bike-based transport. The substitution of manpower for energy, one of the first CE proposals (Stahel, 2019, 1981) is already part of developing countries' reality (Gutberlet et al., 2017).

The CE is then -in general- not institutionalized but operationalized through a bottom-up approach in developing countries[16]. In this context, Diaz (2017) affirms that "efforts should now be focused on assisting those [developing] countries in developing strategies to 'incorporate the recyclers' into the formal waste management process".

[15] In the next chapter, we develop further the role of waste pickers in waste management. See also Ch. 11.

[16] Some developing countries, like China, have their CE strategy, which can be top-down. China promulgated, in 2008, a National Law for the Promotion of the CE. However, some policies related to the CE already existed. Zhu et al. (2019) review 280 related policies that surged after the year 2000. Other low and middle-income countries combine the existence of bottom-up approaches with top-down initiatives to address or strength aspects of the CE.

1.1.8 Summarizing

The aim of this analysis of the roots and approaches of the CE was to summarize their main characteristics and to identify what is the novelty of the field.

When comparing the scope and methods we reviewed of the Sustainable Consumption and Production, Industrial Ecology, and Waste Management fields, with those of the CE (Ghisellini et al., 2016), there is no difference. Reike et al. (2018) arrive at the same conclusion regarding the theoretical underpinnings of CE (systems thinking and circularity). Changing the angle of analysis, Giampietro and Funtowicz (2020) highlight that what is new in this concept is that, for the first time, "different and conflicting perspectives on sustainability seem to agree that the economy needs biophysical inputs (energy and material) for its operation and, therefore, generates outputs in the form of wastes and emissions".

On the other hand, we revealed that the two approaches of the CE (EMF and EU) are different and that none is adequate to the reality of developing countries. Table 1 summarizes the difference we found between EMF and EU CE frameworks and sketches the characteristics of the CE model that prevails in low and middle-income countries.

Table 1: Differences between CE approaches. Source: the author

	EMF	EU	Developing countries
Substance	Model	Plan	Reality
Driver	End-of-life value recovery	SRM and CRM supply Jobs creation	Economic necessity Subsistence
Approach	Horizontal - B2B	Top-down	Bottom-up
Main enabler	New Business Models	Regulations	Waste pickers Secondary (informal) markets
Role of WM in the CE	Not defined	SRM provider Waste hierarchy implementation	Waste pickers organization and integration

Information in Table 1 is only descriptive and of little utility for improving the circularity of materials at any level. Indeed, CE strategies should be adapted to the characteristics of the city, region, or country where they are intended to be applied.

Moreover, the CE approaches alone do not allow us to answer the question which entitles this chapter. In the next section, we analyse this question.

1.2 Beyond the Great Acceleration, beyond waste, beyond circularity

The global trends depicted in Figure 1, even if they bring a "big picture" of the recent pressure on natural resources and the environment, provide only limited information. As Görg et al. (2020, p. 5) point out, "these graphs and the prevailing reading of the Great Acceleration do not allow for a more detailed historical analysis of resource use and its consequences and they also do not give any hints for further deeper analysis". Moreover, this type of analysis hides the past and the existent inequalities in the use of these resources and its link with political decisions or strategies (ibidem).

The Social Metabolism or Socioeconomic Metabolism approach (Fischer-Kowalski and Hüttler, 1998; Pauliuk, St efan and Hertwich, 2015), supported by the use of economy-wide material flow accounting (EW-MFA) and its related indicators (Eurostat, 2018; Fischer-Kowalski et al., 2011; Matthews et al., 2000) is recognized as a suitable tool to analyse the evolution and possible futures of materials flows (Haberl et al., 2019). Also, when combined with historical, political, and economic analysis, they allow for a better understanding of the causes of past -and the challenges of future- socio-metabolic transitions (Fischer-Kowalski, 2011; Haberl et al., 2011; Krausmann et al., 2008).

On the basis of EW-MFA, a set of recent works on global material flows allow for the assessment of the limits and challenges of stabilizing the material flows worldwide and the impossibility of doing so today through the recirculation of materials.

1.2.1 Basic description of the EW-MFA methodology

The current EW-MFA methodology is based on parallel developments made in Japan, Germany, and Austria in the 1990s (Fischer-Kowalski et al., 2011). Its basic principle is that of materials balance, applied to a socioeconomic system defined by several boundaries (ibidem): 1) between the socioeconomic system and the environment; 2) between countries, considering its administrative frontiers and defining imports and exports as input and output flows. Recorded flows are those which cross one of these boundaries[17], and are measured in mass units, generally thousands of tons. Regarding input flows, we can distinguish between used and unused and direct and indirect flows. Used flows are those which have an economic value because they enter the system for

[17] Several conventions have been established, regarding harvested biomass, water flows, balance items, etc. For methodological details see Eurostat (2018).

further processing or consumption, while unused flows cover "overburden and other extraction waste from mining, by-catch, and wood harvesting losses from biomass extraction and soil excavation, as well as dredged materials from construction activities" (Fischer-Kowalski et al., 2011, p. 861). Direct flows are the tons directly recorded in the boundary, while indirect flows are those associated with all the materials required along a production chain to manufacture the product that is recorded at the boundary (ibidem). Indirect flows are important because "the weight of a traded product does not represent the extraction of materials that was necessary to produce the traded product. The material extractions needed to produce a product will always be higher than its simple mass weight" (Eurostat 2018, p. 29). When indirect flows are added to direct flows, we refer to flows in Raw Material Equivalents (RME).

Materials yearly flows are classified in four basic categories: biomass, fossil fuels, industrial minerals and metal ores, and bulk materials for construction. Also, stocks of the system and their variation are registered: flows that will be retained in the economy for a period greater than a year (durable goods and infrastructure), will be accounted for in the "net addition to stock" (NAS) (Matthews et al., 2000).

Several indicators can be calculated as applying the EW-MFA methodology. Figure 9 summarizes these indicators and their relations. Here we will focus on two of them: Domestic Material Consumption (DMC) and Material Footprint (MF).

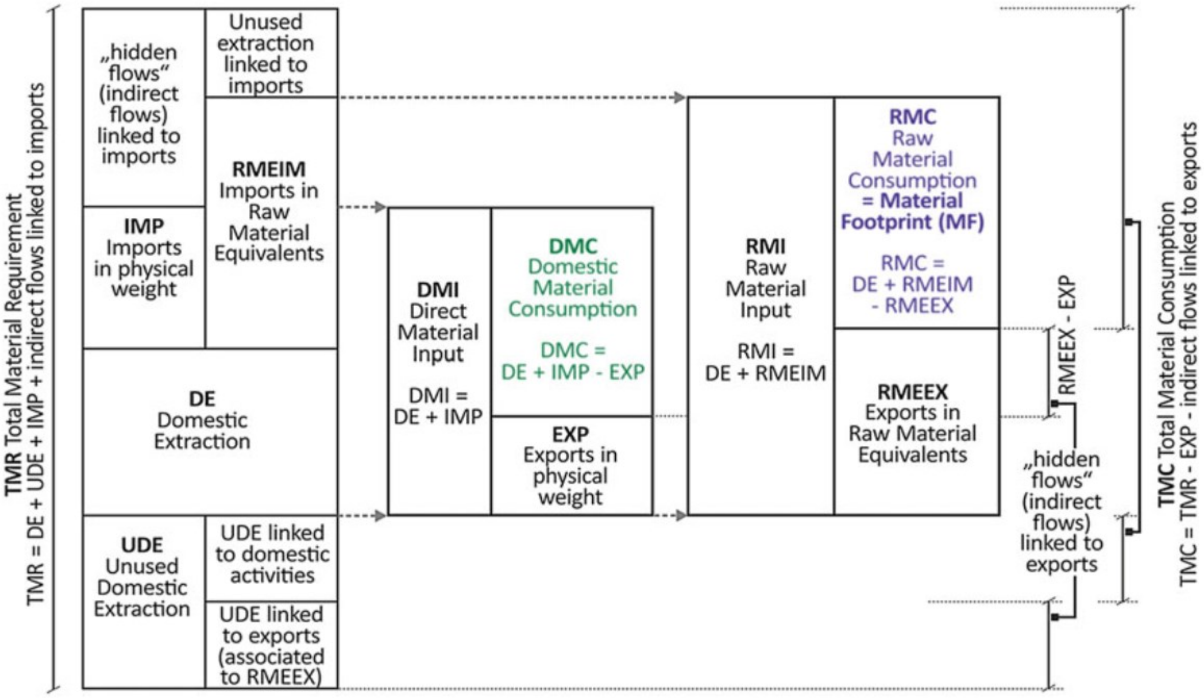

Figure 9: Scheme of EW-MFA indicators as applied by Eurostat. Source: Kusch-Brandt (2019)

DMC is the addition of the Domestic Extraction (DE), i.e. all the materials that enter the economy, and Imports, to which Exports are subtracted. According to the EW-MFA Handbook, “DMC measures the total amount of materials that are directly used in a national economy (...) is the amount of materials that become part of the material stock within the economy or are released back to the environment (DPO)” (Eurostat, 2018, p. 28). Because total DMC of a country will be related to its population, for comparison purposes DMC is commonly analysed per capita, as other EW-MFA indicators.

However, using DMC to measure the level of consumption of a socioeconomic system (for example, a country), is problematic, because it ignores resource consumption and environmental burdens occurring outside the system’s territory. This can be measured if indirect flows associated with imports and exports are recorded and it is what the MF estimates. The MF is calculated as the DE added to the imports in RME, to which Exports in RME are subtracted.

1.2.2 Material flows beyond the Great Acceleration

Figure 10 presents the 1950-2015 evolution of DMC/cap/year and GDP/cap/year, for different country groups. It clearly shows that developed economies took advantage of global material flows. As Schandl et al. (2018, p. 827) state “[l]ow-income countries have benefited the least from growing global resource availability and have continued to deliver primary materials to high-income countries while experiencing few improvements in their domestic material living standards".

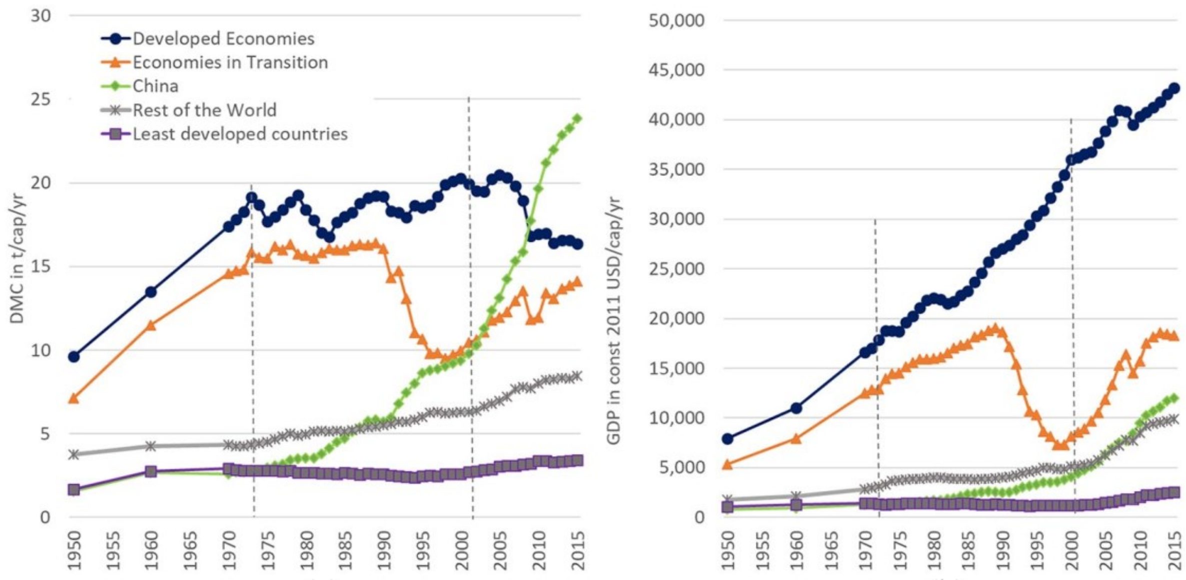

Figure 10: Left: Domestic Material Consumption (DMC); Right: Gross Domestic Product (GDP) per capita. Source: Görg et al. (2020)

On the other hand, the Global Resources Outlook 2019 (IRP, 2019) states that "[t]he material footprint of high-income regions is greater than their domestic material consumption, indicating that consumption in these countries relies on materials from other countries through international supply chains". Indeed, as Görg et al. (2020, p. 6) highlight, "socio-metabolic research has shown that developed economies increasingly rely on imports of resource intensive products; this leads to lower direct resource use and an externalization of resource use impacts from industrialized to developing countries, many of them in the Global South".

Figure 11 shows the evolution of MF for four national income bands. While the MF footprints of high-income countries are near 27 tons per person in 2017, those of upper-middle income group are only 15 tons per person. MF of high-income countries is also more than 13 times the level of the low-income group.

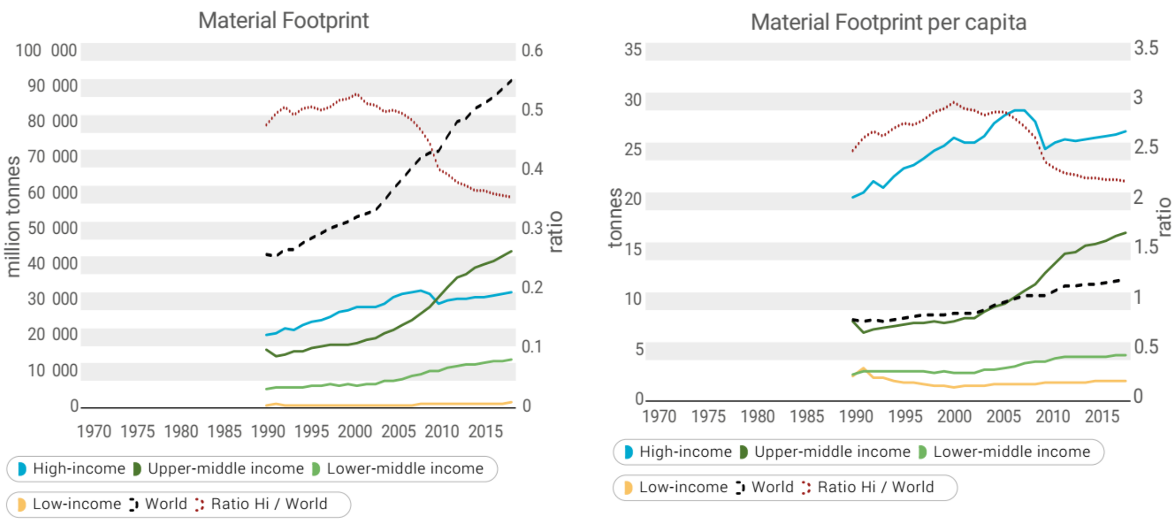

Figure 11: Material footprint and material footprint per capita by revenue sector. Source: IRP (2019)

1.2.3 The limits of circularity

Haberl et al. (2019) highlight the importance of Social Metabolism Research (SMR) to assess circular economy proposals. A high-resolution description of materials cycles is for the authors needed to develop circularity policies. However, the relevance of SMR is also (and maybe mostly) associated with the limits to circularity it allows to put in evidence.

1.2.3.1 Recirculating and stocks formation

EW-MFA studies have shown that material stocks (buildings, infrastructure, machinery) increased greatly during the Great Acceleration. These in-use stocks require flows of materials and energy to perform their services. Krausmann et al. (2017) affirm that half of the current global material extraction is used to build up and maintain stocks. Also, extracted materials are increasingly accumulating in stocks, growing more rapidly than waste generation. Therefore, it is less and less possible to satisfy inputs with recirculated outputs.

1.2.3.2 Recirculating and exponential growth

Grosse (2011, 2010) analyses the implications of the exponential growth of consumption in the context of the circular economy. His results highlight the impossibility of thinking of recycling as a substitute source of primary extractions in a context of exponential growth. There are three factors that must be considered to assess this contribution: a) the percentage recycled; b) the growth of consumption with respect to the previous year; c) the time that products reside in the economy. What

Grosse shows is that, in a context of exponential growth, the effect of recycling is to delay the consumption of raw materials, which will continue to be exponential (Figure 12). This "earned time" is related to the percentage recycled (for example, 80% recycling allows to earn 60 years if we do not consider the materials residence time in the economy). Considering a residence time of 17 years (average value for different products), only a growth of less than 1% per year allows for "earning" enough time to consider a strategy for using resources as "sustainable."

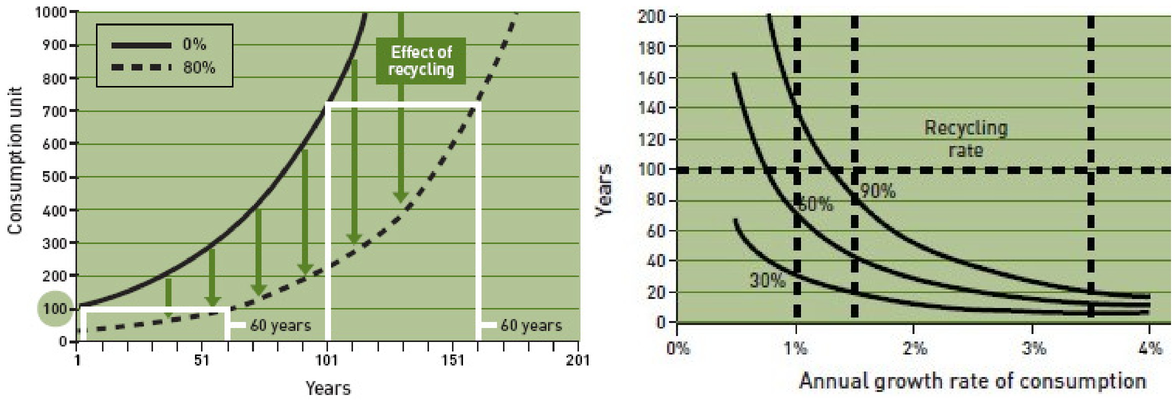

Figure 12: Effect of recycling in a context of exponential growth (left); Effect with residence time 17 years. Source: Grosse (2011).

1.2.3.3 Recirculating and Entropy

The ideal of circularity faces an ultimate limit: The Entropy or second Law of Thermodynamics. This principle defines the irreversibility of many physical processes and the loss of quality (greater disorder) in the overall balance of the system. This implies that to recycle, we will always have to invest energy and that there will always be losses in the process, making 100% of recycling impossible. Therefore, each "loop" in a CE will need flows of materials and energy, which is related to the fact that displacement of primary production, recognized as the main environmental benefit of recycling (Geyer et al., 2016; Zink and Geyer, 2019), is not always possible. In the case of materials used for producing energy, recycling is basically impossible (Haas et al., 2015).

The EW-MFA analysis shows that, at the global level, almost half of materials extracted from the environment are currently used to provide energy without a possible recovery (Krausmann et al. 2017).

1.2.3.4 Other limits

To the limits more quantifiable we mentioned above, we can add other, equally important ones, when analysing the limits of a "circular economy":

- **Dissipative uses.** Many substances (e.g. metals) are used in the form of pigments or additives in inks, paints, surface treatments, or are dissipated during its use (fertilizers). For example, tyres contain zinc and cobalt that will get dispersed in the environment with the wear of the rubber (Bihouix, 2014) and asphalt paints are considered one of the main sources of microplastics arriving to the oceans (Boucher and Friot, 2017). In EW-MFA, dissipative uses (fertilizers) and losses (tyres) are informed as part of the Domestic Processed Output (DPO) but not always calculated.
- **High-tech and new materials.** Many of the technological innovations that are considered key to solve sustainability to, as the renewable energy or the industry 4.0, are based on new materials, new alloys, and complex assemblies. This is translated in challenges when trying to recover these products and (nano) materials, for which there are not yet adequate recycling technologies and for which even the provisioning is not guaranteed in the medium term, such as the case of rare earths (Bihouix, 2014). For Stahel (2019), the recovery of atoms in "the era of D" (D-polymerise, D-alloy, D-laminate, etc.) is a central aspect of the circular economy.
- **Rebound effect.** Also called the Jevons paradox, it is the phenomenon by which the efficiency achieved by new technologies in the use of materials and energy resources do not generate net reductions in its consumption, since they are compensated (or overcome) by an increased use of these new technologies (Polimeni et al., 2015). This results in a global increase in the consumption of materials and energy. For example, the virtualization of the consumption of videos (e.g. movies), which objectively implies less material (CD/DVD) and transport (distribution/video store), resulted in an exponential increase in the video hours consumed that nullifies the efficiency achieved (Zink and Geyer, 2017). In 2016, a study by MIT revealed 57 cases of technological evolution in the use of materials, products and services and found no evidence of dematerialization (Magee and Devezas, 2016).
- **Planned obsolescence.** The concept is well known: many products are designed to have a short life cycle and to force regular new purchases. Despite the negative consequences of this practice, associated with the generation of waste and material and energy misuse, it is difficult to measure the role that this phenomenon plays in the dynamics of our growth economy upon which many jobs are currently supported. This suggests, in some ways, that there are structural economic issues to be solved in conjunction with the problem of programmed obsolescence.

1.2.4 The evolution and the current state of circularity

Recent analyses of the global and historical material flows using the MFA methodology show that the economy is far from being circular (Haas et al., 2020, 2015; Krausmann et al., 2018). Moreover, they show that even in the wealthiest regions, such as Europe, recovered materials represented less than 15% of material inputs (Mayer et al., 2019).

Using the EW-MFA as a basis, Hass et al. (2020) also analysed the evolution of circularity between 1900 and 2015 (see Figure 13).

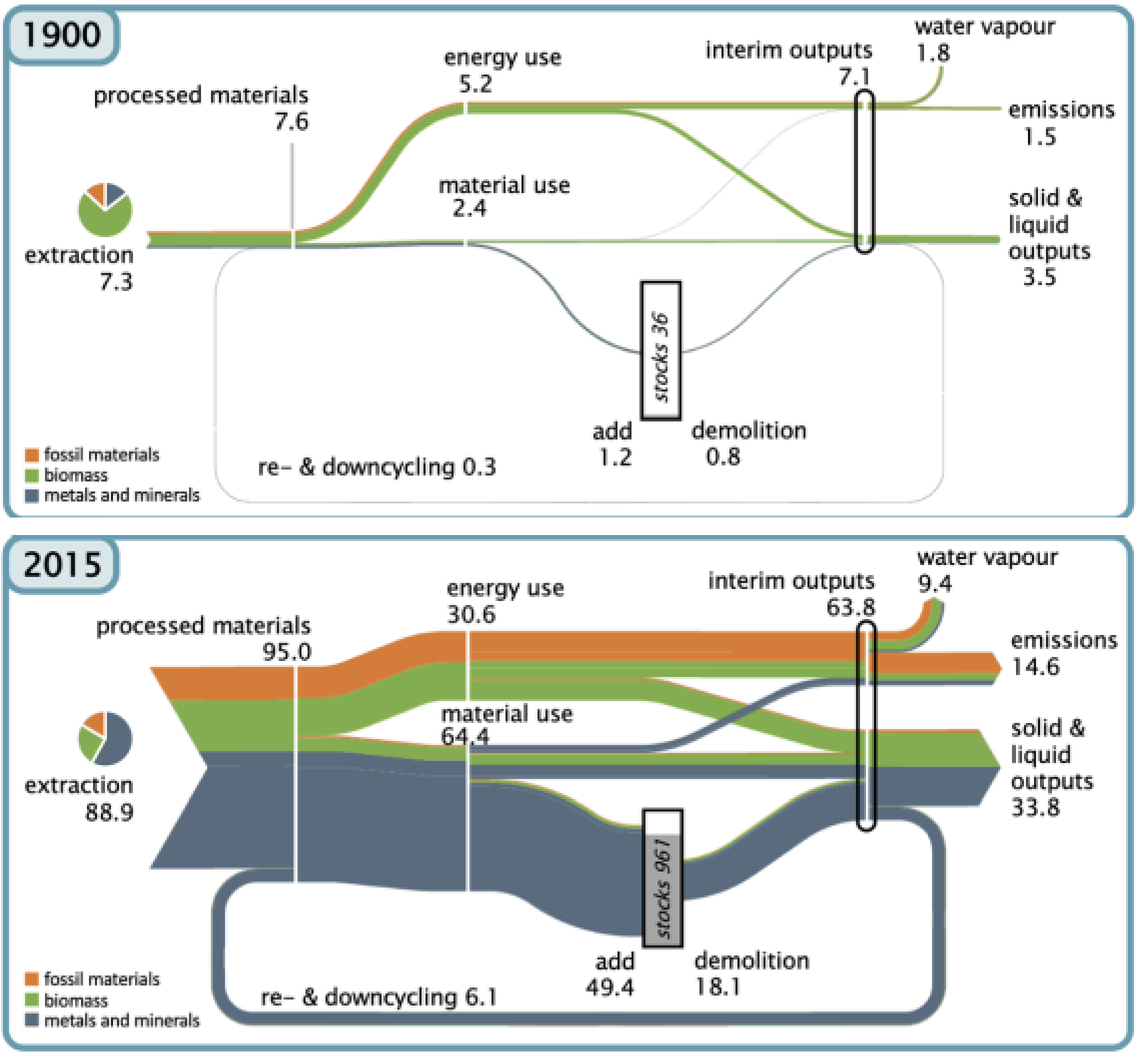

Figure 13: Evolution of the global flows and their circularity for 1900 and 2015. Source: adapted from Haas et al. (2020)

They found that cycling rates decreased in the period: "From 1900 to 2015, input cycling dropped from 43% (41-51%) to 27% (25-30%) (…) and output cycling from 46% (44-54%) to 40% (37-44%). Even if we do not analyse their results in detail, they are related to some of the limits we mentioned in previous paragraphs.

1.3 Conclusion: Why address MSW?

Since this thesis is focused on MSW management (see definitions in the next chapter), we conclude this first chapter by a contextualization of MSW flows and its management.

1.3.1 Municipal Solid Waste (MSW) in the context of global materials flows

The current global MSW generation is 2.01 billion tons and it is estimated to reach 3.4 billion tons in 2050 (Kaza et al., 2018). Moreover, Hoornweg et al. (2015, 2013) estimate that, unless important changes occur in the existing trends of population growth, per capita GDP growth, consumption and management practices, waste generation should not peak before 2100.

As we mentioned earlier, waste management is often used as an equivalent of the circular economy. Therefore, it is assumed that transforming MSW into resources can help to diminish raw materials extraction. Table 2 analyses the percentage that MSW represents with respect to the Direct Material Consumption at different levels.

Table 2: MSW as a percentage of DMC at different scales. Source: the author

	Direct Material Consumption[a] [Gt/year]	MSW generation [Gt/year]	MSW as % of total DMC
World [2016]	89,79	2,01[b]	2,23
Latin America and the Caribbean Region [2014]	7,93	0,192[c]	2,42
Argentina [2014]	0,645	0,018[c]	2,79

[a] UN-IRP (2018)
[b] Kaza et al. (2018)
[c] ONU Medio Ambiente (2018)

This analysis allows us to infer that even an impossible 100% MSW recovery would not have an impact on raw material extraction. At the same time, it serves to reinforce arguments about the importance of the waste hierarchy and the embodied materials of waste.

1.3.2 The importance of MSW in developing countries

Besides the material flow concerns, in developing countries, several reasons make the management of MSW an issue to care about from an environmental sciences angle[18].

[18] MSW is also important for anthropology, history, art, and many other studies.

First, as we will further explain in the next chapter, unsafely managed MSW is associated with health and environmental risks at the local level.

Also, MSW represents high costs for local governments, which most of the times, do not have enough resources. The implementation of expensive recovery strategies that cannot be sustained in time is well documented in the literature (Scheinberg et al., 2010b). Information of waste composition, materials flows, and low-cost recovery strategies are precious in this context.

Finally, recovery of materials is the subsistence activity of many people in low and middle-income countries. They often lack proper working conditions, live under the poverty line with unsatisfied basic needs, and are stigmatized by society. Moreover, MSW plans often ignore them, even if they are, in most cases, the basis of the recycling chain.

2

MSW Management: from the traditional linear approach to the sustainable and integrated approach

When addressing waste management issues, we must be explicit with the definitions adopted. In this Chapter, we will first present the definition of Municipal Solid Waste (MSW) in section 2.1. Then, in section 2.2, we will explore why waste management (WM) is an important issue at the local level. Two main approaches of WM are afterwards presented in section 2.3, namely, the Traditional Linear and the Integrated and Sustainable, which is the most suitable for developing countries. Finally, we close the chapter with an analysis of the role of waste management in the CE in developing countries and the challenges of moving from a Linear Traditional approach to an Integrated and Sustainable.

2.1 Definition of Municipal Solid Waste (MSW)

Defining MSW is important because one of the biggest challenges to compare two MSW management systems (e.g. from two different cities) is that what is considered MSW is different in each case (Scheinberg et al., 2010).

MSW is solid waste generated in urbanized areas. Even if the concept of MSW is simple, its definition is not easy to summarize: it is associated with household waste, even if it also comes from non-household sources; it is distinguished from hazardous or pathogenic wastes, but it contains wastes that can be categorized as hazardous and pathogenic.

Table 3 attempts to reflect this complexity. It crosses the sources of waste generation with the categories of generated waste, and indicates the classification often made with respect to the source of generation (last column). In the last row, we add an operational classification that broadens the definition of MSW, which intends to show that it is also generated in sources that have other types of majority or distinctive waste. In short, we see that MSW includes, to a greater or lesser extent, residues of practically all the analysed categories, which allows us to grasp the challenges associated with its proper management.

Table 3: Different categories of solid waste generated in different sources and general composition (see Scale under the Table). On the right, the different classifications that are given to SW. Below, the extended definition of USW. Source: the author.

Categories / **Sources**	Domestic		Green waste	WEEE	Hazardous	Pathogenic	C&D	**Classification by source**
	Inorganic	Organic						
Households	• • •	• • • •	• •	•	• •	• •	~	Municipal Solid Waste (MSW)
Commerce	• • • •	• • •	~	•	•	•	~	
Institutions	• • • •	• • •	•	• •	•	•	~	
Open/public spaces	• • •	• •	• • • •	~	•	•	~	
Industries	• •	• • •	~	•	• • •	•	~	Industrial Solid Waste (ISW)
Incineration plant	~	~	~	~	• • • •	•	~	
Hospitals	• • •	• • •	~	•	•	• • • •	~	Sanitary Waste
Construction sites	• •	• •	• •	~	•	~	• • • •	Construction and Demolition
Operative classification	Municipal Solid Waste (MSW) *(complement of MSW by source)*							

Scale: ~ negligible; • not frequent; • • frequent; • • • main - not dominant; • • • • main - dominant

The relative contribution of the different sources to the total MSW generated in a city is precious information when we want to define distinct management strategies for each source. The literature is not homogeneous regarding this information, because it can change from one city to another, even in the same country. While some authors estimate that up to 75% of MSW in developing countries may come from households (Scheinberg et al., 2010), others claim that commercial, industrial, and institutional waste generally represent more than 50% of the MSW (Hoornweg and Bhada-Tata, 2012).

The classification by category presented in Table 3 is related to the different treatment technologies or regulations that are often associated with each waste category and that condition them to a certain management strategy. To some extent, it is then arbitrary and not exclusive. Organic waste, for example, could be classified as pathogenic or non-pathogenic. However, classifying waste as pathogenic suggests or implies a certain management strategy and a specific regulatory framework for both organic and inorganic pathogenic waste. It then becomes a dominant category. Therefore, we could also include a column for each waste category requiring a special management (as WEEE in the Table) such as used tyres or medical waste. Importantly, the variety of materials and combinations of materials "inside" each category is considerable. If we think of "inorganic" household waste, we could easily define more than 15 different waste categories. Finally, it is worth considering that there are also other useful classifications for waste, some of which are: regarding its possible reintegration into the productive circuit, we will classify it as recyclable and non-recyclable; regarding its calorific characteristics, we will define it as waste that can be incinerated and waste that cannot; and so on.

The field of Municipal Solid Waste Management (MSWM) is seen as an opportunity for improvement of many aspects of the current unsustainability. According to the Global Waste Management Outlook (UNEP and ISWA, 2015), a global reference document on best waste management practices, improvements in WM could contribute to reducing global greenhouse gas emissions (GHG) by 10-20% annually. The document also states that WM is explicitly and implicitly involved in more than half of the Sustainable Development Goals (SDGs) (United Nations, 2015). Figure 2 shows the SDGs and highlights those in which waste management can play a role (UNEP and ISWA, 2015).

Figure 14: The 17 Sustainable Development Goals (SDGs). Highlighted, those in which WM is at stake according to UNEP and ISWA (2015).

2.2 The importance of MSW Management at the local level

Beyond its global implications, waste management remains a local and urban challenge. If we consider that an urban citizen generates twice as much waste as a rural citizen (Hoornweg et al., 2013) and that the percentage of the world population living in urban areas is constantly increasing -more than 50% since 2008 and 68% projected for 2050- (United Nations et al., 2019), we conclude that cities are fundamental in the search for solutions to the waste problem[19].

Moreover, poor WM generates impacts that are critical at the local level. In cities, all kinds of goods and substances are produced and consumed all the time (Brunner and Rechberger, 2017). Some of these materials will be part of the urban infrastructure (streets, buildings, lighting, etc.) or durable goods (vehicles, industrial equipment, furniture, etc.) for many years. Others will reside in the city for a short time, ranging from some years (appliances, cell phones, clothes, etc.) to some months (various supplies, product packaging, etc.) to some days (food, newspapers, etc.). Once the life cycle of these materials ends, most of them become waste that must be managed.

The majority of this waste is originally inert but valuable if properly managed. However, if this is not the case as in many low- and middle-income countries, waste becomes a threat to public health and to the local environment.

In terms of public health, uncontrolled disposal and burning of waste is associated with direct and indirect risks (Cointreau, 2006). Direct risks are those caused by direct contact with waste. They are related to occupational health and injury issues. More than 40 diseases that can be transmitted by contact (direct and indirect) with waste have been detected (Mesa and Revé, 2001). The most exposed people are informal waste pickers (Gutberlet and Uddin, 2017), residents with poor or inexistent waste collection service, and formal waste workers. In these populations, there is a higher incidence of intestinal parasites than in the general public (Cointreau, 2006). Inhabitants next to sites where burning is frequent may also experience respiratory disorders. This situation is intensified in children, who have a shorter respiratory cycle and not fully developed detoxification mechanisms (Scheinberg et al., 2010b). Indirect risks are related to the proliferation of sanitary vectors such as flies, mosquitoes, and rodents, or to the feeding with waste animals that are then used for human

[19] Of course, all governmental levels are important.

consumption. Finally, waste can also block drains and cause flooding in case of heavy rains, which may drive to health threats. The cholera epidemics in Surat (India) in 1994 (Demaria and Schindler, 2016; UNEP and ISWA, 2015) is one of the best-known examples.

Regarding environmental risks, both surface and groundwater can be affected by waste lixiviates. Its high organic load can produce eutrophication (decreased oxygen available to fish and other aquatic animals due to algal blooms) of watercourses or water reservoirs. Lixiviates often have high concentrations of heavy metals and other hazardous substances (Ishchenko, 2018). Moreover, waste dumping without a protecting membrane may result in soil and groundwater contamination (ibid.). In the case of global warming impacts, GHG emissions (mostly methane) are associated with both uncontrolled burying and engineered sanitary landfills. Paradoxically, in the latter case, the emission of methane is greater, as noted by Scheinberg et al. (2010), because in open-air dumps a partially aerobic decomposition of organic matter is produced (with lower methane emissions).

It is worth noting that the distinction made in the literature between health issues and environmental issues can be associated with a particular worldview. As humans, we are part of the environment and our health is affected by the quality of both the physical environment in which we develop, and the services provided by ecosystems. In the long term, all new substances that enter the economy through innovations (in most cases without any regulation), will end up in the physical environment. The natural environment can process some basic substances if they are adapted (in load and concentration) to the pace of natural processes, but synthetic substances can reside in the natural environment for hundreds or even thousands of years. Moreover, they can accumulate in trophic chains, combine, or degrade, thus resulting in new substances.

2.3 The traditional linear approach of Waste Management

In the previous section, we mentioned that cities concentrate material and energy flows to maintain their structure and activities, generating significant amounts of waste. This waste has been handled differently over time. From the middle of the nineteen century until the ‘70, the main aim of waste management systems was moving waste away from cities, under the paradigm of public health care (Wilson, 2007). With the increased awareness about its environmental impacts, safe waste disposal was also included in the agenda of developed countries (see also Figure 6). These drivers of waste management, i.e. health care and environmental protection, formatted the first definitions of what has been called (integrated) solid waste management. Wilson et al. (2013, p. 53) claim that these definitions are “largely technical, focusing on how to integrate various technical elements into a more complete and/or regional systems”.

Under this view, Tchobanoglous et al. (1982) consider that WM should be done in an “efficient and orderly” way. They group the activities related to WM into 6 “functional elements” defined as stages or activities that follow a certain sequence, as represented in Figure 15. According to these authors, considering each functional element separately allows for (p. 23): “1) the identification of fundamental aspects and relationships involved in each element, and; 2) the development, where possible, of quantifiable relationships with the purpose of comparing, analysing, and engineering evaluating”. Based on this conception, the authors claim that specific solid waste problems may be solved by a solid waste management system through a combination of those functional elements. For them, one of the main objectives of waste management is therefore “the optimization of these systems to provide the most efficient and economical solution” (ibid.). This conceptualization of solid waste management has been replicated countless times. The United Nations, for example, in its Glossary of environmental statistics (United Nations and Statistical Division, 1997) defines the Management of USW as the actions that allow giving a destination to MSW, from its generation to its safe disposal.

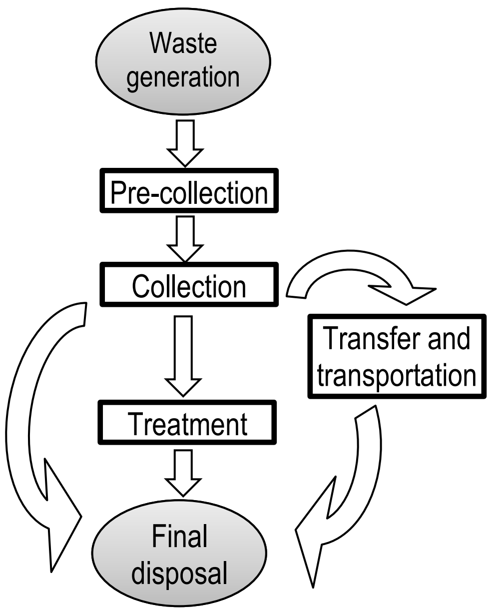

Figure 15: Stages of (traditional) Waste Management. Source: Márquez-Benavidez (2011) (based on Tchobanoglous et al., 1994)

Here we will refer to this conception of WM as the Traditional Management of MSW. Under this traditional management approach, the correct disposal of waste responds to the imperative of protecting the environment and improving the population's quality of life. It is mainly an engineering problem. It is recognized that waste management "includes all administrative, financial, legal, planning, and engineering functions" (Tchobanoglous et al. 1982, p. 18), but the focus is on the technical aspects, as seen in the previous paragraph. The main objective of WM is to correctly articulate the described stages to fulfil the aforementioned drivers. Under this paradigm, Gallardo Izquierdo, and Colomer Mendoza (2011, p. 63) claim that "the main issue in [waste] management is to find an appropriate combination of technologies for each situation".

2.3.1 Characteristics of the Traditional MSW Management approach

Under this approach, the main aim is to know, for each stage or subsystem presented in Figure 15, the parameters that allow for the optimization of the total consumption of resources. Concerning waste generation, the interest is on waste composition, its densities, generation rates (generally in kg/person/day), and their fluctuations both in time and concerning socioeconomic and/or geographical variables. The objective of its study is to properly design the described stages.

Pre-collection, which includes waste handling activities occurring before they are collected, must be adapted to both upstream (to the generation rates) and downstream (to the frequency of collection and their intended treatment, such as separation for recycling, if a treatment is included).

Collection implies "the set of loading-transport-unloading operations occurred between the collection points and the transfer station, treatment facility, or landfill" (Gallardo Izquierdo & Colomer Mendoza, 2011, p. 59). The layout of routes, the choice and maintenance of vehicles, and the frequency of collection, among others, are the parameters that must be defined based on generated waste characteristics and environmental, economic, climatic, urban, and social factors (Coffey & Coad, 2010).

Transfer and transport are stages carried out when the final destination of the waste is far enough to justify its transfer, from a transfer station to a larger transport that optimizes resource consumption.

Waste treatment is the stage where mixed or separated-at-source waste is processed. As a result, we generally obtain materials prepared for recycling or energy, and refuse waste.

Final disposition, the last stage, is ideally done in a sanitary or controlled landfill. If the percentage of the biodegradable fraction is high, the methane generated by decomposition of the organic fraction might be recovered to produce electricity or to be simply burned (reducing the greenhouse impact of emissions).

As mentioned earlier, this conception of MSWM focuses mainly on the related technical aspects, which are multiple. As Table 3 shows, the waste considered as MSW is generated in all the sources described in the Table and includes - to a greater or lesser extent- the quasi totality of the waste categories we have considered. This implies a substantial logistical challenge, since the sources are numerous and the waste generation is continuous, while the disposal sites are usually far from the urban centres. Consequently, given the multiple categories of waste involved and the great heterogeneity of each category, the technical challenges to properly treat them are also very important.

This approach is the current management paradigm of many cities of developing countries, in which efforts are mainly focused on the collection phase (ONU Medio Ambiente, 2018; Risso Gúnther and Grimberg, 2006).

2.4 The Integrated and Sustainable Waste Management approach

From the 2000s onwards, a specialized body of international literature on integrated waste management adapted to the contexts of low- and middle-income countries has been developed. This is in part the result of the formation of an international Collaborative Working Group (CWG) on waste management, which includes academic and non-academic experts. They are responsible for one of the most complete works on the global situation of the integral management of MSW, the book Solid Waste Management in the World's Cities (Scheinberg et al., 2010b). The developments made in this book were then deepened in the Global Waste Management Outlook (UNEP and ISWA, 2015), giving rise to an analytical approach of Integrated Solid Waste Management currently shared by different international actors. The scheme shown in Figure 16 by Wilson et al. (2015) summarizes its main components.

The model was built upon the work started in the mid-1980s by WASTE, a Dutch NGO with a vast experience at working in countries of the Global South, especially in Africa and Asia. It takes the waste hierarchy as a guiding principle and conceives the ISWM as a combination of technical issues related to the infrastructure of the system and its different phases, with governance aspects. Both work in a complementary manner, analogously to the hardware and software of a computer (ibid.).

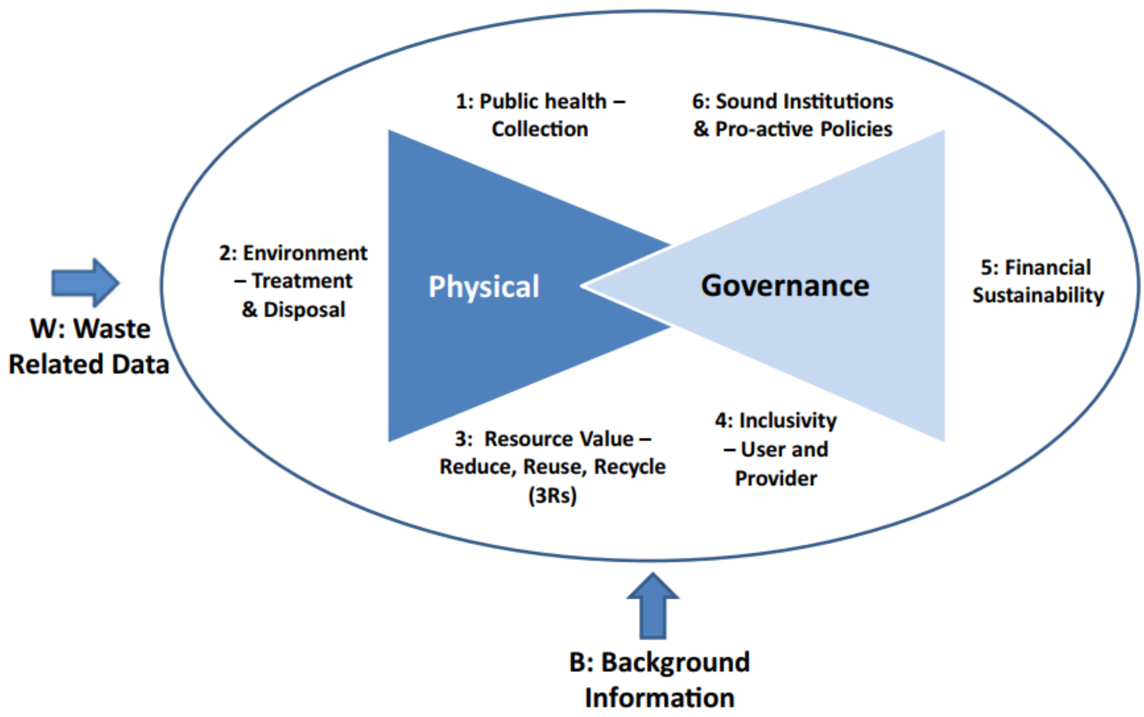

Figure 16: Reference scheme of the Integrated Sustainable Waste Management framework. Source: Wilson et al. (2015)

The three guiding principles or drivers of waste management are included in this framework: the preservation of public health, which is mostly achieved through performant collection and coverage; the protection of the physical-natural environment, which is achieved mainly through the safe final disposal, and; waste management as resources through the 3Rs (Scheinberg et al., 2010b; Wilson et al., 2013). Although these aspects are related to technical issues in the scheme, the analytical approach includes several management aspects that, according to the experience accumulated in developing countries, are the factors that ultimately determine the success of the management programs promoted (Scheinberg et al., 2010b; Wilson et al., 2013; Zhu, 2007).

The three factors of the governance aspects that should be considered for an ISWM are (Scheinberg et al. 2010b):

- *The inclusiveness and participation of all actors*. These include formal service providers, i.e. the different municipal departments involved in the ISWM; private companies and/or associations involved in any of the phases studied; informal providers, such as waste pickers; the generating users; and external agents, such as government agencies.
- *The financial sustainability of the system*. WM systems often represent significant costs for local governments. The increase in the amount of waste generated and the complexity of the products tend to increase these costs over time. In this context, many cities made large investments in projects based on high technologies that they could not finance in the mid-term. This is to be avoided.
- *Policies and laws*. A solid and transparent institutional and legal framework as well as proactive policies are both considered fundamental for the success of any WM strategy.

According to the authors, the 3 guiding principles, their related technical issues, and the 3 management aspects, must all be present in the framework of a comprehensive MSW Management that works in the long term (Scheinberg et al., 2010b; UNEP and ISWA, 2015; Wilson et al., 2012, 2013). It is recognized and emphasized, however, that this approach does not seek to give a “turnkey” response to the problem of waste but to provide a basis of analysis and reflection that facilitates the evaluation of ongoing systems and possible alternatives. On the other hand, it should be noted that, although particular attention is given to financial sustainability, the model considers all the aspects that make the system viable: technical, environmental, financial/economic, socio-cultural, institutional, and political.

2.4.1 Complementary experiences in the LAC region

In order to complete our problem statement, we wanted to highlight some precedents related to ISWM at the regional level. First, the report Guidelines for the Integrated and Sustainable Management of Urban Solid Waste in Latin America and the Caribbean (Risso Gúnther and Grimberg, 2006). This report is the result of the International Seminar on Integrated Management of Urban Solid Waste in Latin America and the Caribbean (LAC), held in November 2005, at the University of São

Paulo, Brazil. In this document, the characteristics of the region are discussed, and case studies are analysed. Also, the meaning of the ISWM in the context of the LAC Region is explored:

> *Integrated management is an interdisciplinary and under construction concept that can be understood from three levels that are closely related:*
>
> *i) A first level refers to the management phases, that is, generation, conditioning, collection, transport, treatment and final disposal with energy, recyclables or biomass recovery;*
>
> *ii) A second level in which the public administration must seek intersectorality, that is, the articulation of the different government sectors involved with the issue of solid waste both in the municipal sphere, and in relation to the provincial, regional and regional public spheres federal;*
>
> *iii) and finally, a third level that presupposes the involvement of multiple social agents in actions coordinated by the public state, that is, to seek the interinstitutionality that involves government, the private sector and society.*
>
> *(Risso Gúnther and Grimberg, 2006, p. 16)*

It is considered that different organizations of society ("NGOs, teaching and research institutions, unions, class associations, media and international cooperation agencies", p.17), as well as informal actors ("the segregator of recycling materials that act in landfills or on the streets, their organizations and also community-based businesses ", ibidem) and the business sector, all "can play a role in the perspective of conventional practices as well as in the construction of more advanced and sustainable solutions related to urban solid waste "(ibid.).

The integration of the MSW Management refers in the report to the importance of achieving an articulation and interrelation in the "normative, operational, financial, planning, administrative, social, educational, monitoring, supervision and evaluation actions for the management of waste, from its generation to its final disposal". The sustainable nature of the system refers to multiple aspects: "environmental, social, economic, health, political, and cultural sustainability" (p. 25).

In general, the approach to the problem proposed in the documents highlighted in the previous paragraphs (Scheinberg et al. 2010; UNEP 2015) agrees with the one made in this regional report. In it, a particular status is given -as in the previous case- to the importance of the inclusion of all the actors in the planning phase, the fundamental role of the legal and regulatory framework, the significance of the "political decision", the adequation to local particularities, and other aspects of management:

> *It is essential for the achievement of integrated management to perform participatory diagnoses, strategic planning, as well as the integration of sectoral public policies and respective bodies together with civil society and the private sector. In this way, it is necessary to create mechanisms for the shared implementation of actions, evaluation and monitoring instruments and, not only, the option of appropriate technologies, to move towards the sustainability of solid waste management.*
>
> *(Risso Gúnther and Grimberg, 2006, p. 16)*

2.4.1.1 ISWM, strategic planning and continuous improvement

Kunitoshi Sakurai, a consultant for the Pan American Health Association (PAHO) (1979-1984) and of the Japan International Cooperation Agency (1985-1992) who worked on waste issues in the LAC region, wrote the report "Improving Solid Waste Management in Developing Countries" (Sakurai, 1990). In this book, result of his years of field work in Latin America, Sakurai puts planning at the centre of the ISWM. First, he explains the importance of developing a National ISWM Plan. The reasons put forward by Sakurai for this are: 1) to efficiently manage the scarce resources of developing countries; 2) to achieve a harmonious development of the ISWM area with respect to other public services; 3) to better coordinate, with local governments, the creation of urban land and the ISWM, environmental education, the development of local machinery (adapted to local conditions), and the search for new sites for landfills. Sakurai proposes that a national agency responsible for the National Plan develop a preliminary report consisting of a conceptual framework and an action plan, answering the Why, What, and How of the national strategy (Sakurai, 1990, p.15).

In chapter 3 of his book, Sakurai focuses on the local level (municipalities). He highlights the rapid changes that were occurring in terms of the increase of MSW generation, its greater complexity, and the increasing demands by users regarding the WM service. Sakurai affirms that these aspects will characterize the challenges of the WM for the municipalities of developing countries. Given these changes and the need to improve the service efficiency, Sakurai states that "only a systemic approach consisting of planning, implementation, monitoring (evaluation), and plan readjustment can achieve these objectives [the increased efficiency and the reduced costs] continuously" (Sakurai, 1990, p. 40).

Although Sakurai does not include any reference for this statement, it is clear that he was incorporating the theoretic-practical advances of the total quality management (TQM) field. TQM was developed after World War 2 but when he wrote his book it was particularly advanced in Japan, its country of origin. In this sense, Sakurai seeks to apply the concept of continuous improvement or Deming Cycle (see Figure 17), that is, the foundations of strategic planning (Vinzant and Vinzant, 1999), to the MSW management.

This approach to the problem is repeated in the literature. Pírez and Gamallo (Pírez and Gamallo, 1994), similarly, define 6 phases of the waste management service: 1) Policy elaboration; 2) Planning; 3) Inversion; 4) Execution, 5) Operation; 6) Monitoring. It is detailed, also, in the Technical Guide 86 of the Colombian Institute of Technical Standards and Certification (ICONTEC) called Guide for the implementation of Integrated Waste Management (ICONTEC, 2003). This Guide is based on the phases of the Traditional Management of MSW, but frames all these activities within a cycle of continuous improvement. Figure 17 summarizes these characteristics.

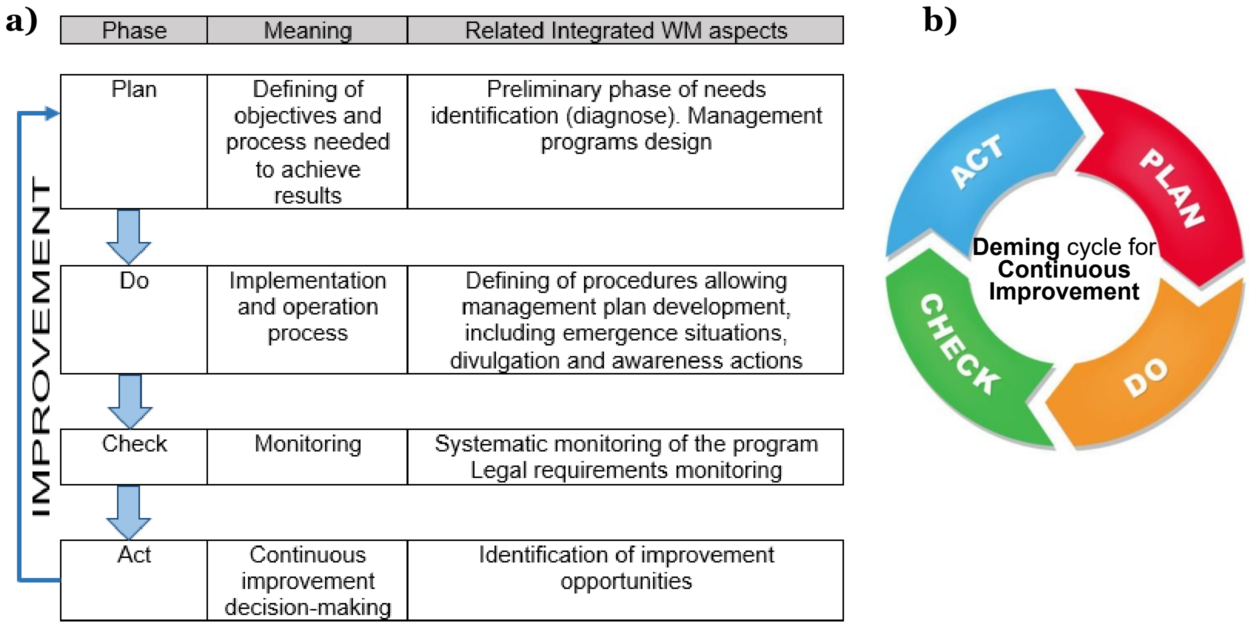

Figure 17: a) Model of Integrated Solid Waste Management included in the GTC 86 (ICONTEC, 2003). b) Continuous improvement Deming cycle

Another example in the same line is the General Law for the Prevention and Integral Management of Waste of Mexico. In its article 26°, the Law establishes that local governments must elaborate and implement Municipal Programs for the Prevention and Integral Management of the MSW (PMPGIRSU). These programs should include, at least (Wehenpohl and Hernández Barrios, 2006):

- a basic diagnosis of the integrated waste management of the municipality
- the local policy on MSW and on special waste (they are also regulated by this Law)
- the definition of local objectives and goals for the prevention of generation and the improvement of the MSW and special waste management, as well as the planned strategies and deadlines for compliance
- the financing strategies of the actions considered in the programs
- the mechanisms planned to improve the linkage between different municipal programs, in order to create synergies

In Costa Rica, the national Solid Waste Plan (PRESOL) proposes Municipal Plans for Integrated Solid Waste Management (PMGIRS), which are conceived as "basic tools for technical and financial planning, and to implement an optimized and sustainable management at all stages of the ISWM" (CYMA, 2008). The development of these Plans is justified because it is considered that "when waste management is not planned, it is difficult to obtain or guarantee an efficient use of resources: human, technical, financial, material, as well as time" (ibidem, p. 14). Planning is considered as a process by which a long-term vision is defined, with short, medium and long-term goals. Once the action plan is launched, the essential element is, according to the authors of the PMGIRS Development Manual, its monitoring, evaluation, and implementation.

2.4.1.2 ISWM and Inclusive Recycling

When we reviewed the concept of Integrated and Sustainable Waste Management, we referred to international work based on concrete experiences in developing countries (Scheinberg et al., 2010b; UNEP and ISWA, 2015; Wilson et al., 2012, 2015). The resulting reference analytical framework for ISWM is summarized in Figure 16. In these publications, and in many other based on experiences in different cities of the Global South (EIU 2017; IDB 2013; Scheinberg 2012; Gunsilius, Bharati, and Schein 2011; Scheinberg et al. 2010), the authors highlight the key role of the informal recycling sector (IRS) for the ISWM. The IRS is responsible for the achievement of high recycling rates in many cities, comparable in some cases to those achieved in developed countries.

In Delhi, for example, waste pickers recover 27% of USW, that is, 1800 tons of waste every day (Scheinberg et al., 2010b); in Cairo, 60% (ibidem). In Montevideo, 65% of what is recovered is the work of waste pickers (Bidegain, 2011); in Santiago de Chile, it is the 70% (CONAMA, 2005), while in Buenos Aires city, the 95% (AVINA, 2013).

Thus, it is the waste pickers' daily work what has the recycling value chain work. The economic benefits, however, are inversely distributed, as schematized in Figure 18.

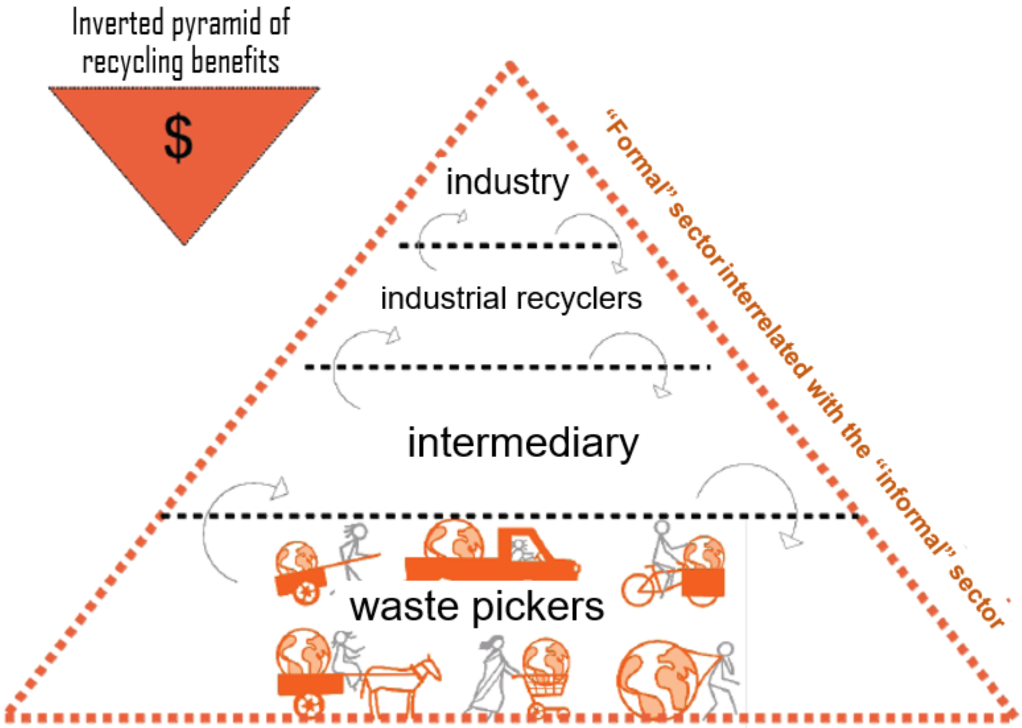

Figure 18: The pyramid of the recycling value chain and the inverted profit pyramid. Source: Modified from WIEGO (2013)

From the 2000's, the conception of the IRS made by researchers, institutions, and governments has changed. The first approaches, which could be considered as "development interventions" (Scheinberg, 2012), were focused on how to solve or diminish IRS vulnerability. As Fernández Gabard (2011) points out, under this approach "the recycler is seen as 'an informal to formalize'". The "assistance" proposed by institutions and governments aimed at improving specific aspects of the "vulnerability problem", such as eradicating child labour and improving the working conditions (safety) of waste pickers, etc. Soon, these approaches showed their limitations since they failed to promote substantial changes in the role of the waste pickers in waste management systems and their sustainability (Scheinberg, 2012).

In the last decades, WM modernization projects have also been implemented in many developing countries (Demaria and Schindler, 2016). They aim to copy the experience of developed countries in the 1980s and 1990s. Indeed, in response to the first environmental protection laws of the 1970s, these countries incorporated recycling into the integrated management, establishing a virtuous circle of citizen engagement, investment, and development of the value chain. Importantly, it was based on local technological developments and appropriate incentives (Scheinberg, 2012). Also, many countries incorporated Waste-To-Energy technologies as a complement to recycling.

Idealizing the "mine" of resources in waste and the power of technology, many cities in developing countries (e.g. Cairo, Delhi, or Varna) promoted projects based on the incorporation of imported technology, obviating the work of waste pickers and the economic and environmental benefits they generate. This resulted in conflicts over recoverable materials, lower recovery rates, and higher costs (ibidem)[20].

2.4.1.3 The Informal Recycling Sector (IRS) organization in the LAC region

Parallel to this evolution in the conception of waste pickers' role in WM, there was a phenomenon of organization of the IRS at different scales: local, regional and global. In comparison with other regions of the World, LAC is considered to have an advanced level of organization of the IRS (Ezeah et al., 2013). Built upon more than 10 years of isolated but important experiences mostly from Brazil and Colombia, the Latin American and Caribbean Network of Recyclers (Red LACRE) was formed in 2003, year of the first Latin American Waste Pickers' Conference (Red LACRE, 2013). Between 2003 and 2007, several regional articulation meetings preceded the 2008 third Latin American Waste Pickers' Conference and first International World Congress of Waste Pickers (Booner, 2008). This Congress was attended by 35 countries from Africa, Asia, Europe and the Americas, as well as representatives from governments, NGOs, Foundations, companies and microenterprises, researchers and international cooperation agencies. At that moment, alliances between waste pickers organizations and international organizations like the Avina Foundation, the Collaborative Working Group on Solid Waste Management (CWG) or WIEGO (Women in Informal Employment: Globalising and Organising) were well advanced, providing sound bases for growth at regional and international levels.

At the LAC regional level, with the support of the Avina Foundation, the Multilateral Investment Fund (Inter-Development Bank) and private companies, the Regional Initiative for an Inclusive Recycling (IRR) was launched in 2011. The IRR aims at "improving the socio-economic conditions of waste pickers through their recognition in public policies and waste management systems and their access to markets" (IRR, n.d. our translation). Their work includes the training of key actors, an open-

[20] The Environmental Justice Atlas (see https://ejatlas.org/) recently included a new category of waste-related conflicts. Most of them are related to WM modernization plans.

knowledge hub development, and “inclusive recycling” project financing with local partners.

In the LAC region, inclusive recycling has been adopted as a new key-concept.

> *Inclusive recycling is understood as those waste management systems that prioritize recovery and recycling, recognizing and formalizing the role of recyclers as key actors of such systems (…). These systems are built through regulations and public policies, initiatives, programs and actions of the public and private sectors. Recycling with Inclusion represents a new paradigm in the sustainable management of solid waste, which incorporates into the concept of environmental “3 R” (Reduce, Reuse and Recycle), other “3 R socio-economic”, namely:*
>
> - *Differentiated waste collection*
> - *Recognition of the role of recyclers*
> - *Remuneration for the service they provide*
>
> *EIU (EIU, 2017, p. 15)*

According to the Red LACRE (Alaniz and Schaeffer, 2017, p. 3), inclusive recycling must guarantee the rights to:

1. Stay in the trade
2. Free association and integration in the recycling value chain
3. Formally articulate with the formal waste service and to receive a payment for the services provided
4. Promote decent work
5. Participate in the construction, implementation, and monitoring of waste management policy frameworks

At the global level, in recent years further work with WIEGO after 2008 resulted in the creation of the Global Alliance of Waste Pickers, aimed at improving the living and working conditions of the IRS by strengthening solidarity and mutual learning between countries (Fernández, 2011). Through this Alliance, waste pickers take part in the United Nations Climate Change Conventions.

2.4.1.4 The IRS inclusion in other contexts

The IRS is less and less considered as an obstacle to development and increasingly as a pillar of sustainable development that needs to be strengthened. The World Resource Institute (Chen and Beard, 2018) adopted a similar position regarding the informal sector in general, considering the waste pickers as central actors.

Another concrete example of this change is their recent incorporation into the family of Guiding Principles of the International Organization for Standardization (ISO) of the Guidance for the Sustainable Management of Secondary Metals (Valdivia et al., 2016). Based on the fact that the IRS is responsible for 90% of the secondary metals that are recovered from waste, it is the first ISO document that incorporates waste pickers as key actors.

Finally, we can mention the Sustainable Recycling Industries Program (SRI), funded by the Swiss State Secretariat for Economic Affairs (SECO), and implemented by the World Resources Forum (WRF) and the Swiss Federal Institute for Materials Science and Technology. This program focuses on the issue of WEEE management in emerging and developing countries and seeks to facilitate the development of policies that recognize the fundamental contribution made by waste pickers, providing appropriate methodological approaches (Méndez Fajardo et al., 2017).

2.5 Conclusion: How to move from the linear to the integrated model and what is the role of waste management in the circular economy in developing countries?

Table 4 summarizes the differences between the ISWM approach and the traditional Management approach. First, their general approach differs, and they are fashioned by different drivers of WM. Therefore, they have different main objectives. Then, the processes analysis in the TWM follows a linear conceptualization, while in the ISWM the vision is systemic. Another fundamental difference to highlight is that in the TWM the focus is on the “optimization” of the described linear stages, while in the ISWM it is about achieving an effective coordination through a strategic management. Another difference lies on how decision making is carried out. In ISWM, participative instances are implemented, and in the case of developing countries, this is made with special concern regarding the inclusion of informal actors.

Table 4: Differences between Traditional Waste Management (TWM) and Integrated Sustainable Waste Management (ISWM). Source: the author.

	TWM	ISWM
Main approach	Engineering	Management
Driver	Protecting health and the environment	Waste as resources
Main objective	Safe disposal	Waste hierarchy
Process conceptualization	Linear	Systemic
Main problem-solving strategy	Optimization (technical)	Strategic management (PDCA for continuous improvement)
Decision-making	Centralized (Municipality)	Participative and inclusive

It is important to note that these are ideal-type characterizations. In general, MSW management systems combine characteristics of both approaches. Moreover, different degrees of implementation of each characteristic can co-exist, for example, regarding participation and inclusion.

2.5.1 The role of waste management in the circular economy in developing countries

The waste management conception of the most widespread CE frameworks (see section 1.1), does not allow us to grasp the challenges associated with it in developing countries.

As we showed in this chapter, even the Traditional waste management framework allows us to understand how difficult it can be to cities to implement and coordinate all the stages of waste management. MSW management deals with thousands, hundreds of thousands, or millions of generators of waste every day. Moreover, the waste composition and therefore the possible treatment of waste -to a large extent- are not defined locally.

For cities in developing countries, the government must also consider the work of the informal recycling sector, and more broadly with informality in many aspects (non-declared commercial activities, waste processors, etc.). On the other hand, CE frameworks are based on strategies that are beyond the realm of local governments, even if they must be operationalized at the local level.

Considering the information presented in previous and current chapters, we consider that a better representation of the role of waste management in a CE for developing countries is presented in Figure 19.

The model presented in Figure 19 seeks to highlight some central aspects of the relationship between ISWM, IE and SCP (see previous chapter), considering these fields as the macro-constitutive strategies of the CE that need to be analysed in their interaction.

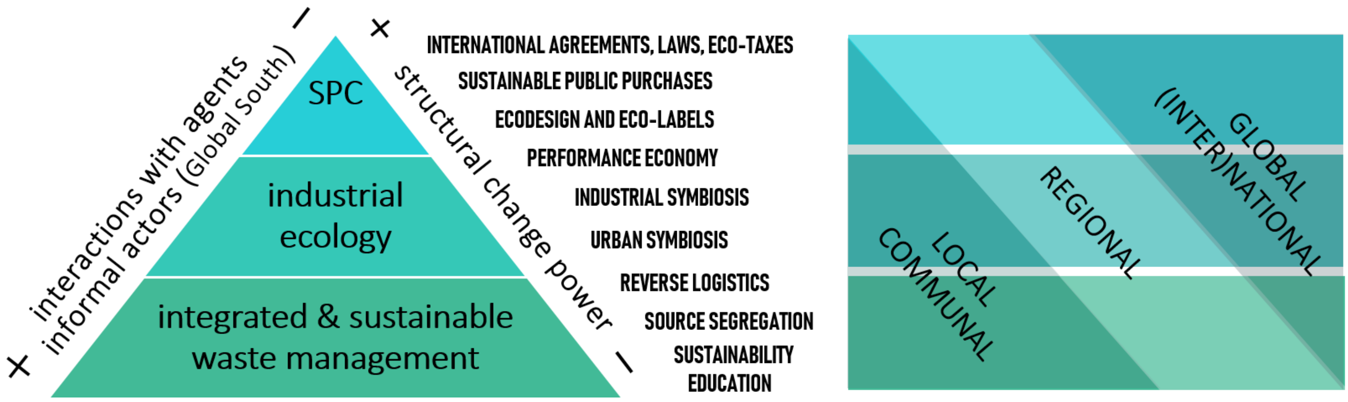

Figure 19: The CE as an integration of ISWM, Industrial Ecology and PCS. Left: Structural relationship; Right: Relevance of the scales of action (local / communal, regional / provincial and global / -inter-national) in each of them. Source: the author.

The pyramid in Figure 19 does not represent a hierarchy since sustainability in the resource management requires all three options to be implemented simultaneously. The pyramid shape responds to the extension of the fields, in relation to the number of interactions with agents or actors that each one involves.

On the right of the Figure, the bands indicate at which level each field corresponds. At the local level, waste management is the central strategy because it is operationalized at this level. The possibilities of link flows from the city with industries, in urban symbiosis, and that of promoting industrial symbiosis in/or eco-industrial parks, make the IE field the second of importance at this level. Finally, SCP is less relevant, even though strategies like sustainable public procurement (SPP) or eco-taxes can be applied at this level.

At the regional level, the three fields have a relevant impact. Industrial ecology maintains a greater balance between the scales involved, although the regional scale slightly prevails. Flexible regulation is crucial to achieve the implementation of industrial symbiosis and waste regulations are generally given at the regional-provincial level (Costa et al., 2010). Also, Baccini and Brunner (2012) suggest this level is adequate to perform urban metabolism studies and territorial interventions. Many regulatory and institutional SCP strategies can be applied also at this level, such as SPP, eco-taxes, eco-labels, etc.

SCP is the most relevant strategy at the national or international level because it is mainly a top-down approach and its origins are the international agenda (see previous Chapter). Several IE tools may be applied at the national level, while some waste management regulations, such us the banning of one-use plastic or of organic waste disposition in landfills.

Connecting these levels may improve the results of policies at all levels. It would be of interest to dig deeper into this analysis, although it is beyond the scope of this work.

2.5.2 How to move from TMW to ISWM?

Knowing what a better WM could be is not enough. Velis (2017) remarks that, in the past, addressing WM problems in a simplistic way resulted in “landmark failures”. Furthermore, he states that innovative and combined actions between academics and practitioners are needed. As in many other environmental issues, current WM practices in cities respond to multiple factors. Moreover, since the conception of a problem naturally condition how the system under analysis is approached, implications are high in terms of considered methodologies, the nature and scope of the improvement proposals and the interpretation of the obtained results.

It is then important to explore what kind of epistemological approaches and methodological tools are needed to pass from a TWM system to an Integrated Sustainable one. However, these aspects are poorly addressed in MSWM literature.

Therefore, in the next chapter, we will reframe the analysis of the waste management within what is called the Persistent and Complex Problems (PCP) in cities.

3

Persistent and Complex Problems (PCP) in cities: definitions and approaches

Although by definition we should try in the first place to avoid waste generation, economic activity -one of the main drivers of waste generation today (Hoornweg and Bhada-Tata, 2012; Kaza et al., 2018)- is undoubtedly one of the most common political objectives for local governments, since it is directly related to employment generation and social welfare. On the other hand, consumers often cannot choose packaging-free products or do not know where to bring recyclable waste if there is no source-segregation where they live (the previous step to any valorisation strategy). To make matters worse, and under the simplistic and short-term view of traditional economic sciences, the costs associated with adequate waste management will always be higher than those of a baseline scenario in which waste is "simply" buried. Also, as seen in the previous Chapter, that apparently “simple” scenario represents, in itself, a very important logistic and management challenge. Therefore, several questions arise: What can local governments do against an economic model based on consumption growth? How do you reconcile the conflicting objectives of improving recycling and reducing costs in a context of budget adjustments? How do you adapt the infrastructure designed to optimize waste burial when you want to optimize recovery and recycling, too? How do you change the cultural habits rooted in society to generate new behaviours?

These are the types of problems are known as "persistent problems" (Grin et al., 2011) or "wicked problems" (Rittel and Webber, 1973). We argue that the Traditional WM can be considered a “persistent complex problem”, and that the transition from a TWM to an Integrated WM should be approached as transitions in complex problems.

In this Chapter, we will first describe this type of problems in section 3.1. Then, in sections 3.2-3.5, we will present different approaches advanced in literature to address them: interdisciplinarity, post-normal science, transdisciplinarity, and other complementary fields.

3.1. Persistent Complex Problems (PCP)

The concept of “wicked problems” was introduced by Rittel and Webber (1973), who referred in this way to public planning problems for which, they affirmed, “it has become less apparent where problem centers lie, and less apparent where and how we should intervene” (p. 159). They distinguished the urban planning challenges of the second half of the twentieth century from the more "engineering" problems of the nineteenth and early twentieth centuries.

Some characteristics of these types of problems are (Elmqvist, 2018; Grin et al., 2011; Haan and Heer, 2015; Rittel and Webber, 1973):

- there is no definitive formulation of them
- they have complex causal chains and it is not possible to "understand" them completely
- they are related to processes that are inflexibly embedded in societal structures
- there are many actors involved and each actor has a different view of the problem (and there are no “wrong” views)
- there are many possible alternatives to change the current situation
- objective information is scarce, uncertainty is high, and it is difficult to evaluate the alternatives
- there are economic restrictions and political and cultural barriers to overcome
- the problem is related to other problems with same characteristics.

Here we will refer to this type of problems as persistent complex problems (PCPs). PCPs generally involve multiple levels of political, economic, and social organization, and it is not possible to apply optimality criteria; there are no optimal solutions, but "best possible[ones]" (Haan and Heer, 2015). In most cases, changes to be made are so significant that they imply a transition in the social and infrastructure system that may take decades to concrete. It is the case, for example, of the energy transition, or of the transition to a sustainable transport system. Both problems can be defined as PCPs and are very closed related. Other problems of this type are climate change, comprehensive water resource management, urban planning, biodiversity conservation, etc. (Rayner, 2006).

As mentioned in previous paragraphs, this type of problems and the challenges they entail have been detected for decades. From decades, different approaches have emerged seeking to address these "real-world problems", involving both theory and practice from different conceptual and epistemological perspectives and defining new relationships between "science" and "society". In what follows, we will present some relevant theoretical elements and then, we will focus on current approaches intending to address PCPs.

3.1.1 Complexity and complex systems

From a theoretical point of view, addressing complex problems involves challenges that are both philosophical (epistemological) and scientific. In the first case, the characteristic radical uncertainty of these problems (already conceptualized by F. Knight and JM Keynes in the 1920s) confronts with some of the basic premises of the so-called Cartesian knowledge paradigm, which -in its desire to isolate and specialize knowledge to understand problems- is inadequate to deal with many real-world problems.

According to García[21] (2006, p. 21), it is Edgar Morin who has contributed the most to “demolishing the foundations of traditional rationalism”. In his book "Introduction to complex thinking" (2011), Morin advances some key basic premises. First, that complexity cannot be explained only through a definition, even less as the opposite of simplicity. Although that “complexity appears where the simplifying thinking fails”, it “integrates as much as possible the simplifying ways of thinking, but rejects the mutilating, reductionist, unidimensionalizing and finally blinding consequences of a simplification that is taken as a reflection of what would be real in reality” (p. 22). Complexity, then, emerges as a new paradigm which differs substantially from the "mechanistic-reductionist-deterministic" approach of science, which claims that we can know the functioning of the whole through the study of the parts.

From an analytical point of view, a new field of knowledge that gives a theoretical framework to this new paradigm has been in development since the mid-20th century. The *complexity sciences* are built on the bases of two intertwined disciplines, systems theory, and cybernetics (Hafferty and Castellani, 2009). The first was formalized with

[21] Rolando García (Azul, Buenos Aires, 1919-2012) was an Argentinian politically engaged scientist, co-founder of the National Council for Scientific and Technical Research (CONICET) and pioneer developer with Jean Piaget of the genetic epistemology field.

the work of biologist Ludwing von Bertalanffy and his General Theory of Systems (Bertalanffy, 2003 [1968]). The second, developed by mathematicians, neurologists, engineers, and sociologists, unravelled the mechanisms by which systems self-regulate and self-organize.

The *emergent properties* of complex systems cannot be attributed to any of their elements, but rather, derive from the structure of the system and the interactions that occur between its elements (Hafferty and Castellani, 2009). Two important characteristics resulting from the interaction between the elements of a complex system are *non-linearity* and *feedback loops*. Non-linearity is the non-directly proportional reaction that usually exists between a change in an internal or external factor of a system, and the response of the system to this alteration. Feedback loops play a crucial role in the self-regulation capacity of complex systems. They are simply a causality chain between different elements of the system that allows the inputs of a process to be related to the outputs of the same process, resulting in loops that can be of *reinforcement* (positive) or *balance* (negative).

An example of a positive feedback loop is given in the context of global warming, with the albedo effect (Steffen, 2005). The more the average temperature increases (especially at the poles), the more the surface reflecting part of the energy the Earth receives from the sun decreases, resulting in a relative increase in the average temperature (since more energy is absorbed). This accelerates the loss of albedo surfaces, giving rise to a positive feedback loop that will continue to reinforce until a negative feedback loop will compensate for this phenomenon.

Other properties of the complex systems relieved from the literature by Castellani and Hafferty (ibid.) are:

- complex systems are dynamic, that is, their behaviours change over time and they are subject to “path dependence”
- they are agent-based. They are built “from the ground” as a result of the interaction of their agents (although they are influenced by the environment since they are open and dissipative systems)
- they follow rules that determine the interactions between agents
- They self-organize, that is, they follow a pattern of organization without the need for an external force to "direct" their actions

- they operate far from equilibrium, in a stability that is maintained by a constant flow of energy (and in some cases also material) that allows for the development of their internal complexity
- they are part of a larger network of systems
- they evolve and can adapt to external or internal changes through their communication methods (feedback loops);
- they have emerging properties that need to be studied in a holistic way

To end this brief treatment of the topic, we will comment on three related concepts related to the dynamic evolution of complex systems, which characterize the behaviour of many of these types of systems: *attractors*, *thresholds,* and *critical transitions*. Attractors in complex systems are state configurations the system tends to converge to. The equilibrium of the system around each attractor is stable (complex systems may have more than one). If the disturbances or changes in the structure of the system are very large, there is a possibility that a threshold is crossed (or that it disappears) which causes the system to pass from a state of equilibrium to another state of equilibrium. These changes are generally abrupt, following a non-linear behaviour. This is what we call critical transitions, bifurcations or regime shifts and that have been verified in numerous social systems (Centola et al., 2018), in the so-called socio-ecological systems (Gunderson and Holling, 2002) and also in the socio-technical systems (Geels, 2005).

The relationship between complex systems and wicked problems is evident. PCPs involve one or more complex systems and must be addressed under the complexity paradigm. This complexity poses important methodological challenges when it comes to solving these types of problems.

3.2 From interdisciplinarity to postnormal science

Along with the new paradigm of complexity, new methodological proposals emerged to determine how to approach the PCPs and who should be involved in the problem-solving dynamics. As Morin opportunely argued in Method I, complex knowledge must necessarily have a new way of acting “that does not order, but organize; does not manipulate, but communicate; does not direct, but encourage” (Morin et al., 2010, p. 436).

One of these first responses that emerged to tackle PCPs was interdisciplinarity. In 1948 already, W. Weaver, in his famous article “Science and complexity” (Weaver, 1948), highlighted the importance of the “mixed-team” approach of operation analysis during wartime to solve what he called problems of “organized complexity”.

Rolando García (2006) states that interdisciplinarity is an appropriate methodology to address problems of the “real-world”, which are always complex:

> *In our conception of complex systems, what is at stake is the relationship between the object of study and the disciplines from which we carry out the study. In this relationship, complexity is associated with the impossibility of considering particular aspects of a phenomenon, process or situation from a specific discipline.*
>
> *In other words, in the "real world," situations and processes are not presented in a way that can be classified by correspondence with any particular discipline. In that sense, we can talk about a complex reality.*
>
> *Garcia (2006, p.21)*

Interdisciplinarity appears to García as an appropriate methodology for the study of "environmental problems"[22] which cannot be studied through the addition of disciplinary studies. García differentiates the interdisciplinary from the “disciplinary integration”, the latter being the mere formation of multidisciplinary teams in which “the results of different studies on a common problem” are integrated. García affirms that, in interdisciplinarity, “the integration of the different approaches starts in the delimitation of the problem” (ibidem, p.33) instead. That is, it implies conceiving the problems under this paradigm from the beginning and not only "adding" contributions made by each researcher from his or her particular discipline. García goes even further and claims that interdisciplinarity also requires “a common conceptual basis and a shared conception of scientific research and its relations with society” (ibidem).

[22] According to Garcia, "environmental problems" are those "such as unhealthy living conditions in large urban centres, or the problem of the physical environment and living conditions spoilage in large regions" (2006, p. 87). This definition corresponds to what we have called, following other authors, “persistent complex problems” or PCPs.

In this sense, a fundamental issue in the interdisciplinary complex systems ("real world") research is how the science-society interface is conceived: "it is essential that this awareness [on the construction of the study object and on how society conditions that construction] stays in permanent tension". In this type of problems, "social factors play a fundamental role" (p.34).

According to García, this conception, together with a distinct "hierarchy of values", is what should be shared among all the members of the interdisciplinary team. They ultimately determine the type of questions the research will seek to answer, to which gathered data "in the field" will be given greater importance, and what actions will be taken to "modify" the system.

It is necessary to note, however, that to García addressing complex "real-world" problems is primarily an expert issue[23]. In this sense, its position clashes with other approaches that, to address these types of problems, propose a co-production of knowledge that involves both academic and non-academic actors.

3.3 From postnormal science to transdisciplinarity

In the 80s, Silvio O. Funtowicz and Jerome R. Ravetz proposed the concept of postnormal science, a "problem-solving strategy" designed for cases in which "the facts are uncertain, the values are in dispute, what is at stake is high and decisions are urgent" (Funtowicz and Ravetz, 1993a, p. 22)[24].

The starting point of the Funtowicz and Ravetz approach is the complexity paradigm (Funtowicz and Ravetz, 1996). Their proposal is based on a critique of the assumptions of modern science, according to which "uncertainty was the result of human passions" and "ignorance would be conquered by the power of reason" (ibidem, p.7). The development of the scientific method, whose objective was to discover "pure" facts (free of values), was based on the study of isolated components of the natural system and on the supposed possibility of separating the object and the subject of study. This gave

[23] García (2006) affirms: "interdisciplinarity involves the integration of different disciplinary approaches; for that, each member of the research team must be an expert in its discipline" (p.32). In this aspect, García followed Piaget (1972), who was its colleague and mentor. In the transdisciplinarity field (see next section), this conception is referred by some authors as Mode 1 transdisciplinarity (Scholz and Steiner, 2015a).

[24] Funtowicz and Ravetz refer to complex problems, environmental problems or global (risk) environmental issues (Funtowicz and Ravetz, 1997, 1996, 1994).

rise, according to Funtowicz and Ravetz, to the "myth of neutral science, free from values" (ibidem).

On this basis, a particular conception of the relationship between the State (or politics) and science is constructed, in which it is considered that the latter, through the provision of adequate information, facilitates rational decision making. Thus, under this construction, discovering the true facts”, Funtowicz and Ravetz point out, allows “right decision making” (ibidem).

However, complex systems have fundamental uncertainties associated, related to both the limitations of our current knowledge (classical uncertainty) and our ability to know (radical, irreducible uncertainty). And as we saw above, persistent complex problems also have these properties. As Gallopin et al. summarize (2001, p. 223): “[t]he complexity of the system to be dealt within the domain of sustainable development is one of the most critical arguments for the need for changes in the production and utilization of science”.

Figure 20 schematizes the framework of postnormal science developed by Funtowicz and Ravetz. The illustration relates aspects of knowledge and aspects of values, related to scientific knowledge. If we consider that science is traditionally associated with certainty and neutrality, the evidencing of the uncertainty associated with complex problems is an innovative conception. In this conceptual framework, "systems uncertainties" means that "the problem is concerned not with the discovery of a particular fact (as in traditional research), but with the comprehension or management of a reality that has irreducible complexities and uncertainties” (Funtowicz and Ravetz 1994, 1882). By "what is at stake in the decision", they mean the various costs, benefits and evaluative commitments that will be at stake through each person who participates in the creation of scientific knowledge.

The first problem-solving strategy of the postnormal conceptual framework is the so-called applied science, which can be used, according to the authors, when uncertainties have a technical level and can be handled with standard and routine procedures (tests, statistics, etc.). The results obtained by the researchers may or may not affect them as individuals and, in general, the success of their research is followed by great uncertainty about the possibility that the purpose in which the work is framed will succeed (Funtowicz and Ravetz, 1994).

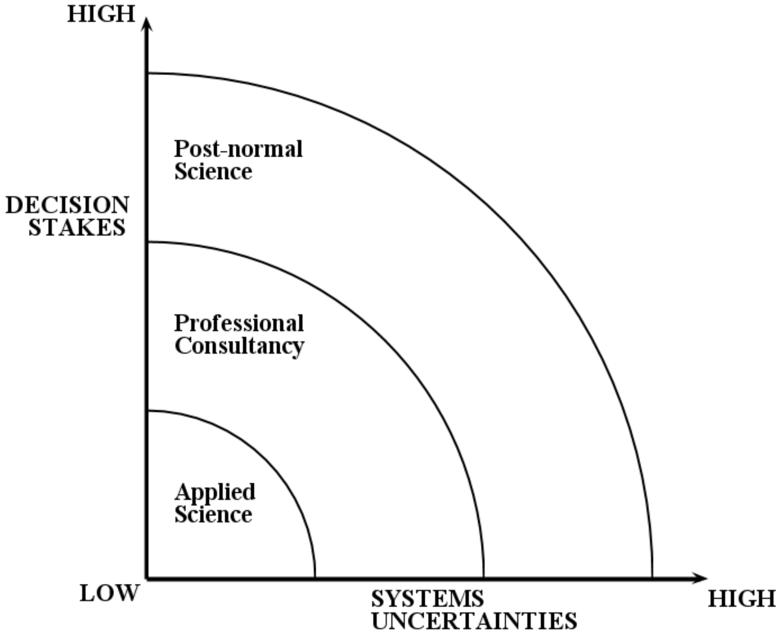

Figure 20: The postnormal science framework. Source: Funtowicz and Ravetz (1993)

Professional consulting is related to specific problems (and not reproducible, contrary to the case of applied or basic science), in which there are uncertainties at the methodological level (for example, in the models used). The experience of the consultant then becomes relevant, as does the reliability of the available information, and there is a responsibility for the work done.

In postnormal science, the uncertainties are epistemological (irreducible) and/or ethical and there are conflicts of values among the multiple actors involved. Although applied research and professional consulting are part of the development of the problem-solving strategy, they do not dominate the decision-making process (ibidem). The quality of knowledge that is input of this process must be evaluated by an "extended peer community" that involves multiple actors, as opposed to the case of traditional science where the quality of inputs and findings are evaluated only by "peers" scientists (Funtowicz and Ravetz, 1997).

The postnormal science approach, thus, implies a new configuration with respect to the science-society interface. Civil actors are an integral part of a horizontal research process, in which the work dynamics, conceptualizations, and roles of those involved are not the same as in the traditional approach to science or the interdisciplinary approach. As Funtowicz and Ravetz (1996, p. 8) say, "[t]o deal with these new issues, science divided into disciplines has to become transdisciplinary science, and reason must be reconciled with passion”. It is this new practice what they call “postnormal science”.

3.4 Transdisciplinarity: research, process, and challenges

In practice, postnormal science has mainly been a vision that nurtured different approaches (Dankel et al., 2017; Frame and Brown, 2008; Ravetz and Funtowicz, 1999). Its call to the existence of an “extended peer community” prompted the plurality of knowledge in the political debate, a claim that appeared mainly in related fields, such as sustainability sciences (see for example Miller, 2013; and Villalba, 2016), but also in others (see below). This new configuration of actors poses important epistemological challenges since it is about (co) constructing knowledge *beyond* disciplines.

One of the fields that deals with these challenges is transdisciplinarity. According to the Handbook of Transdisciplinary Research (Hirsch Hadorn et al., 2008, p. 4), transdisciplinary research “aims at identifying, structuring, analysing and handling issues in problem fields with the aspiration ‘(a) to grasp the relevant complexity of a problem (b) to take into account the diversity of life-world and scientific perceptions of problems, (c) to link abstract and case-specific knowledge, and (d) develop knowledge and practices that promote what is perceived to be the common good”.

From a Western experience, Scholz et al. (2006, p. 227) defines transdisciplinarity as “a process of mutual learning and joint problem solving, in which scientists from different disciplines collaborate with practitioners to solve real-world problems”. From a Latin American perspective, Delgado and Rist (2016) define transdisciplinarity as a “heterodox epistemological-ontological front” aimed at “the co-production of knowledge among scientific, indigenous, peasant, urban communities and their social, political or cultural movements interested in looking for alternatives beyond the reproduction of current forms of societal organization and modern western science” (Delgado and Rist 2016, 36).

A multiple referenced definition of transdisciplinarity is given by Lang et al. (2012, pp. 26–27)[25]: “Transdisciplinarity is a reflexive, integrative, method-driven scientific

[25] This definition is reproduced in several publications as attributed to Lang et al. (2012). However, as signalled by the same authors, it is an adaptation of Matthias Bergmann’s definition of transdisciplinarity in the launching conference of the International Network for Interdisciplinarity and Transdisciplinarity (INIT) in Utrecht, The Netherlands, in 2011.

principle aiming at the solution or transition of societal problems and concurrently of related scientific problems by differentiating and integrating knowledge from various scientific and societal bodies of knowledge".

The origins of transdisciplinarity can be traced back to the work of Jantsch (1972, 1970), who called for the redesign of the education/innovation system to respond to societal system goals based on an emerging epistemological pattern. He asked for a reform of universities through the adoption of a "transdisciplinary structure" that would have, for example, function-oriented departments such as housing and urban transportations, or system-design laboratories for socio-technological systems, such as public health and urban living. Later, Gibbons et al. (1994) introduced the concept of Mode 2 knowledge production, which served to delimit Mode 2 transdisciplinarity from Mode 1 transdisciplinarity, i.e. what we called interdisciplinarity[26] in the previous section.

Mode 2 transdisciplinarity, also referred to as "Zurich 2000" definition of transdisciplinarity" (Scholz, 2011b; Scholz and Steiner, 2015a)[27], has also been differenced from a "post-normal science" transdisciplinarity (ibidem). Scholz (2011, p. 378) affirms that "in the Zurich 2000 definition, science refers to a normal science view (i.e. approaching a valid or "true" description of reality as a reference system) which is lost in the post-normal variant". However, Scholz finds more commonalities than differences between both.

Scholz (2011) also distinguishes between transdisciplinary research and process. The transdisciplinary process refers to the collaborative space in which members of the science and society interact to generate social robust knowledge through mutual-learning (ideally) in a power-balanced relationship. Transdisciplinary research refers to the preparatory, support information, or follow-up research that takes place before, after or during the transdisciplinarity process and that is controlled (ibidem).

Other authors do not make a distinction between both and refer to a "transdisciplinary research process" (Bergmann et al., 2012; Jahn et al., 2012; Lang et al., 2012). Lang et

[26] Scholz and Steiner (2015a) explain that this delimitation is necessary because of the Piaget's reference to "full transdisciplinarity" (Mode 1 transdisciplinarity) which is, as we said above, what we called interdisciplinarity.
[27] It is called in that way because it was formulated during the International Transdisciplinarity Conference in Zurich, in which 500 researchers and 300 practitioners attended (Thompson Klein et al., 2013).

al. (2012), based on the previous work of Jahn (2008), present a conceptual model of an ideal-typical transdisciplinary research process (see Figure 21).

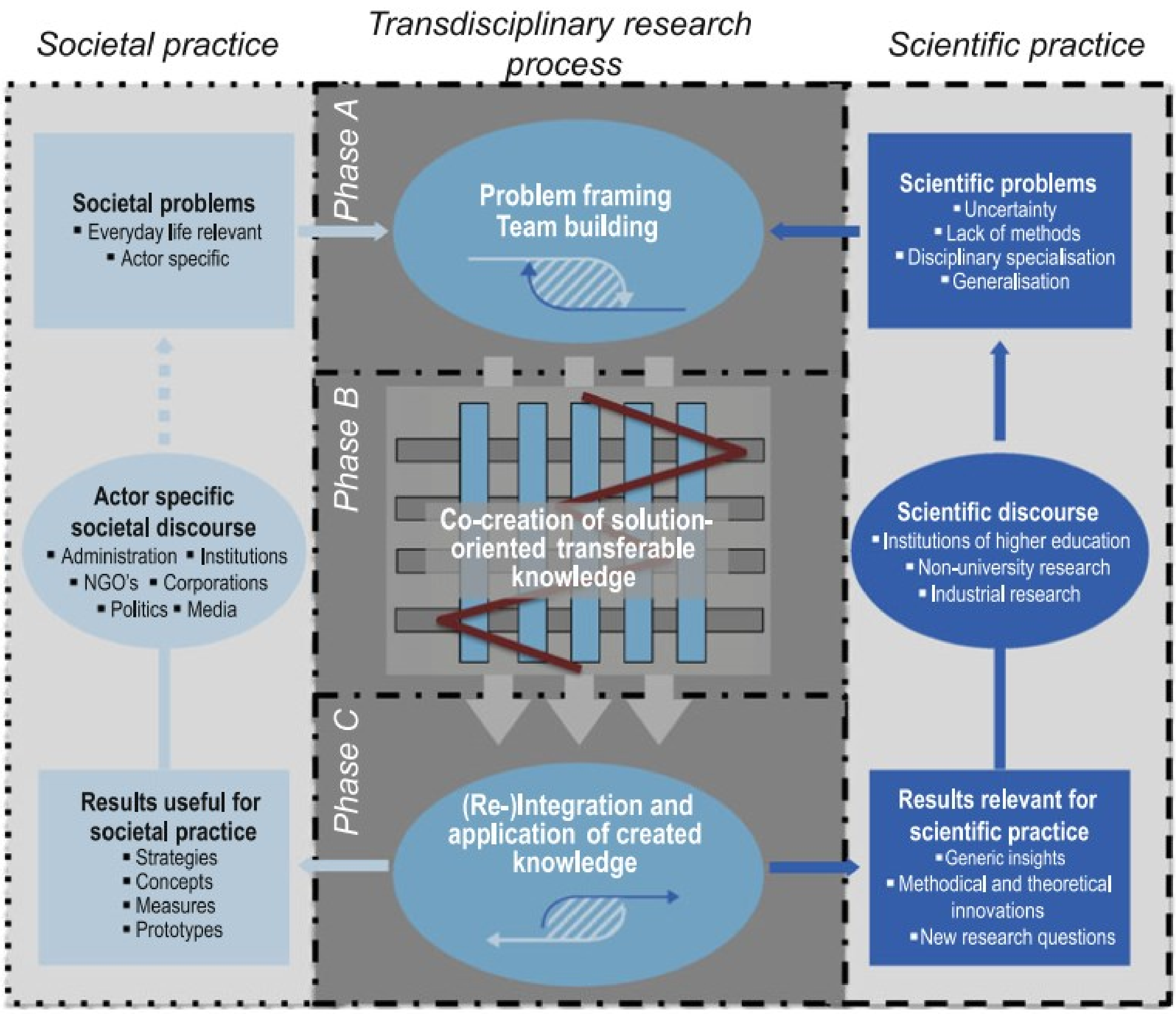

Figure 21: The conceptual model of an ideal-typical transdisciplinary research process formulated by Lang et al. (2012)

According to this conceptual model, a transdisciplinary research process consists of three phases that are often performed iteratively or recursively (Lang et al., 2012): A) collaboratively framing the problem and building a collaborative research team; B) co-producing solution-oriented and transferable knowledge through collaborative research; C) (re-)integrating and applying the produced knowledge in both scientific and societal practice.

From the previous paragraphs, we can understand that implementing transdisciplinarity is not straightforward. As Delgado and Rist (2016) affirm, the scientific knowledge creation approach implies an important challenge, which consists of "finding ways to stimulate dialogue and cooperation between heterogeneous groups of social actors with different forms of knowledge, instead of impose a single 'coherent' view of the world (...) that silences all other discourses and is placed outside the object of the analysis" (Delgado and Rist 2016, 41).

Scholz and Steiner (2015b, p. 522) claim that, for applying transdisciplinarity (Td), there are "epistemic, methodological, and practical challenges to overcome in order to determine the right path at each crossroad, junction, and complex roundabout as well as several multi-level, nodal points of communication". Therefore, they distinguish (Scholz and Steiner, 2015a, p. 531) between the "ideal type" transdisciplinarity, i.e. "a simplified description of what constitutes transdisciplinarity" of the "real type" transdisciplinarity, i.e. "a very complex and ambitious venture whose multiple objectives are difficult to realize in practice" (Scholz and Steiner, 2015c, p. 653).

Pohl et al. (2010) state that co-production of knowledge condition conventional research practices and the roles that researchers may play in research processes when finding themselves in a situation of "divided identity" (scientific/decision-taker). Additionally, they identify the main challenges related to structuring a space for co-production of knowledge: power, integration, and sustainability. In the first case, the challenge is to make sure that the process is not confiscated by any stakeholder such as elites and the government. This implies the "[n]eed to advocate the co-existence of thought collectives and thought styles and make these explicit" (p.271). In the case of integration, the authors refer to "interrelating epistemological, conceptual and practical elements that were not related before" (pp. 271-272) intending to achieve "a more comprehensive, or — in terms of power and thought styles — more balanced and adaptable understanding of an issue and corresponding solutions" (p. 272). In short, that is to ensure that a common understanding of the issue at stake is shared. The last challenge identified by Pohl et al. (2010), the sustainability challenge, is specific to projects working under the "sustainable development" realm. The challenge is to ensure that the knowledge co-production accords to the "normative framework" of sustainable development.

3.4.1 Transdisciplinarity projects and the three types of knowledge

The aim of co-work with different stakeholders to address real-world problems implies, in general, that transdisciplinarity must be carried out by means of mid- and large-scale projects (Binder et al., 2015; Schneider et al., 2019; Scholz and Steiner, 2015c; Wiek et al., 2012)[28].

For better framing Td projects, upon the vision of research for sustainability of Swiss researches, it is possible to identify three types of knowledge that research questions should address (Binder et al., 2015; Pohl and Hirsch Hadorn, 2007):

- Knowledge about what is (systems knowledge). It is related to questions about the genesis and possible development of a problem and its life-world interpretations. It provides information about the structures, processes, and problems of the system.
- Knowledge about what should be (target knowledge). It is related to questions about determining and explaining the need for a change, what the desired goals and better practices are. It has a normative component.
- Knowledge about how we come from where we are to where we should be (transformation knowledge). This knowledge is related to "questions about technical, social, legal, cultural, and other possible means of acting that aim to transform existing practices and introduce desired ones" (Pohl and Hirsch Hadorn, 2007).

3.5 Selected complementary approaches, concepts and tools

In the previous sections of this chapter, we first introduced the concept of persistent complex problems and then we explored some epistemological approaches emerged in the last decades that are intended to address this type of problems. Now, we will briefly review some complementary approaches, concepts, and tools that can help to conceptualize WM as a PCP[29].

3.5.1 Participatory democracy, hybrid forums and controversies analysis

The need to include new actors in seeking for solutions to real-world problems finds echoes, in our opinion, in some connected fields aiming to enhance democratic processes. This concern makes sense if we consider that, if the solution to a PCPs

[28] The authors note that small-scale projects with time and finance constraints also exist. However, they affirm that "there have been very few successful studies of transdisciplinary process that have been run independent of mid- or large-scale transdisciplinary processes".
[29] There are similar approaches to transdisciplinarity that are not reviewed here (see Scholz and Steiner, 2015b for a summary). Instead, we focus on independent fields that tackle other aspects of the solving of real-world problems.

implies changes in the structure and organization of cities, it should be part of a democratic process.

First, we identify the participatory democracy and governance literature. In relation to the postnormal science approach -which they criticise- Wesselink and Hope (2011, p. 390) highlight that "[g]etting things done in the policy arena involves more than providing the right science: it involves doing politics, that is, using power and influence strategically". They signal that Funtowicz and Ravetz proposal of the extended peer community lacked the explanation of how its implementation would result in finding remedy to the pathologies of the global industrial system. Moreover, they affirm that, even when the postnormal science authors try to differentiate their approach from "merely politics or public participation" (Funtowicz and Ravetz, 1993, p. 751), "dealing with values and stakes and deciding who may or may not sit at the policy table may be exactly what politics and public participation are all about" (Wesselink and Hoppe, 2011, p. 392).

Bacqué et al. (2005) claim that participative democracy emerges as a response to a lack of legitimation of the institutional system. This crisis of politic representation and forms of government is in turn exacerbated by the legitimation crises of the scientific and technical domains, which have historically served to legitimate political decisions: "ecological, urban, or health challenges, which are becoming significant at the local level as well as at a global scale (…), question the society's capacity to deliberate democratically on fundamental scientific and ethical issues and, therefore, the status of scientific research" (p. 11).

This double lack of legitimation has been approached in the literature of Science and Technology Studies (STS). The field of the STS connects the debates related to governance and participatory democracy with those related to controversies analysis and the technical democracy (Callon et al., 2009; Pestre, 2007). At the same time, it connects the controversies analysis and technical democracy field, with that of transdisciplinarity.

According to Callon et al. (2009), controversies take place in public spaces they called *hybrid forums*. They are forums "because they are open spaces where groups can come together to discuss technical options involving the collective", while they are hybrid "because the groups involved and the spokespersons claiming to represent them are heterogeneous, including experts, politicians, technicians, and laypersons who consider themselves involved" (ibidem, p. 18).

Controversies analyses are therefore considered important for us because they can fulfil a double purpose in the context of PCPs. First, controversies are seen as a tool for the improvement of the democratic process and for learning (Callon et al., 2009). Hybrid forums, for example, have already been used to give dynamism to the public debate around sustainability issues, thus allowing for a better framing of complex problem (Amilien et al., 2019). Another reason for considering these analyses important is that, when proposing a solution to a PCP, any technological choice or program will be naturally controversial.

3.5.2 Boundary work, boundary objects and boundary organizations

Another set of concepts developed to understand different arrangements in which knowledge links to action is that of boundaries work, objects, and organizations. These concepts highlight the dominance of different norms and expectations in experts and decision-makers communities (Cash et al., 2003).

Boundary organizations are defined as organizations that (Guston, 2001, pp. 400-4001): 1) "provide the opportunity and sometimes the incentives for the creation and use of boundary objects and standardized packages" (see below); 2) "involve the participation of actors from both sides of the boundary, as well as professionals who serve a mediating role"; 3) "exist at the frontier of the two relatively different social worlds of politics and science, but they have distinct lines of accountability to each".

Boundary objects are outputs or results of the work in boundary organizations that "are both adaptable to different viewpoints and robust enough to maintain identity across them" (Star and Griesemer, 1989, p. 387). In some cases, a boundary organization can also be a boundary object (Guston, 2001).

The main idea of the *boundary work*[30] is that tensions arise in this interface and they need to be managed (Clark et al., 2016): if the boundary is impermeable, there is no meaningful communication; if the boundary is too porous, "the special value of research-based knowledge fails to materialize" (p. 4615). Complementary, Cash et al.

[30] The concept of boundary work was initially developed to study the demarcation of science and non-science activities by scientist (see Gieryn, 1983 and ; Guston, 2001).

(2003) call *boundary management* the work of “[o]rganizing and facilitating co-production of knowledge at the interface of science and society” (Miller, 2013, p. 287).

The concepts of boundaries work/object/organization are part of the transdisciplinary literature. Pohl et al. (2010) consider boundaries organizations as an alternative option (to transdisciplinarity) for the interactive production of knowledge between different actors. They focus on the definition of boundary organizations given by Guston (2001) for whom co-production of knowledge is associated with the co-production of knowledge and social order, as understood in the context of Science and Technology Studies (S&TS) (see Jasanoff, 2004). Pohl et al. (2010) declare to agree with this conception but point out, however, that a difference exists in how knowledge is produced in one and another option[31]. In transdisciplinary sustainability research, they argue, the aim is “to produce an agora in which the boundaries are provisionally blurred” (p. 270; see Figure 22). About this article however, Guston (2001, p. 399) affirms that “[t]his work finds that the blurring of boundaries between science and politics, rather than the intentional separation often advocated and practiced, can lead to more productive policy making”[32].That is because, as we saw, the work in boundary organizations does not mean to keep boundaries impermeable.

[31] Pohl et al. (2010) therefore compare definitions that are at different levels of analysis: Jasanoff (2004, p. 3) affirm that “[c]o-production can therefore be seen as a critique of the realist ideology that persistently separates the domains of nature, facts, objectivity, reason, and policy from those of culture, values, subjectivity, emotion, and politics”.

[32] Moreover, in the Conclusion he affirms (p. 405): “It should not be worrisome that the implementing of boundary organizations may at times be characterized by a political intrusion into the workings of science, largely because there is a reciprocal intrusion of science into politics”. And later, “The boundary organization does not slide down either slope [the slippery slopes of politicization of science or scientization of politics] because it is tethered to both, suspended by the coproduction of mutual interests”.

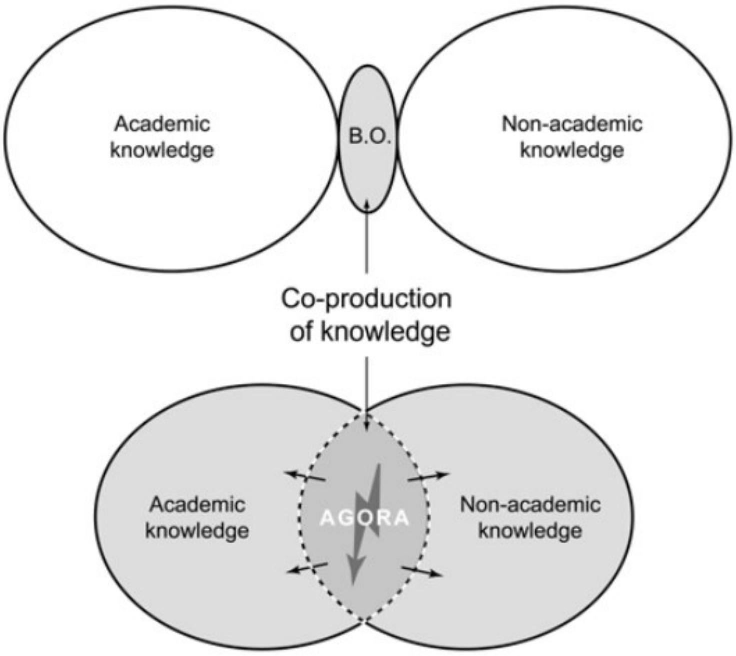

Figure 22: Pohl et al. (2010) conception of the difference between boundary organizations and transdisciplinary co-production of knowledge. Source: Pohl et al. (2010)

Pohl et al. (2010) associate boundary organizations with what Miller (2013) refers to as the *knowledge-first* sustainability science approach, in which "the problem of sustainability [is seen] as a problem of decision-makers not using available knowledge due to lack of credibility or legitimacy, having insufficient knowledge or not having knowledge about the necessary aspects of the system" (Miller, 2013, p. 287). Miller also identifies the *process-oriented* sustainability research approach, in which "the focus is on setting up, participating in and conducting research on social and technological processes attempting to define and move towards sustainability" (ibidem). This approach, he argues, simultaneously "creates a space for science as a source of credible knowledge and limits its own epistemic authority by acknowledging that it is just one source of such knowledge among many" (p. 288). For Miller, however, boundary management is present in both approaches.

Other strand of transdisciplinarity literature consider, as Miller, that boundary organizations are a constitutive part of transdisciplinarity. For Lang et al. (2012, p. 28), the construction of a boundary object "that is both researchable and allows for the re-integration of the insights into societal implementation as well as the scientific body of knowledge" is an essential part of the transdisciplinary process. In the same strand, Cockburn et al. (2016) consider the building of a boundary organization as a key phase of the transdisciplinary process.

In summary, the boundary concepts we defined in the previous paragraphs may be part of transdisciplinarity research.

3.5.3 Transitions research: sustainability transitions and transition management

Transition research is a relatively recent body of knowledge comprising a wide diversity of approaches and perspectives used in different way to address Persistent Complex Problems (Loorbach et al., 2017). It is considered an inter- and transdisciplinary field, based on Mode 1 and Mode 2 research (see previous section), closely connected to innovative practices (Loorbach, 2007).

In the context of transition research, the term transition "refers to the process of change from one system state to another via a period of nonlinear disruptive change" (Loorbach et al., 2017, p. 605). One of the main hypotheses in the field is therefore that it is possible to influence these processes of societal change if the mechanisms and dynamics of transitions are better understood (Loorbach, 2007). In this sense, the scope of the transitions studies is to understand past transitions but also to support problem structuring, reflexive capacity and social learning to fashion spaces of change that allow transition pathways to emerge through avoiding the lock-in situations that characterize wicked problems.

3.5.3.1 The Multi-Level Perspective (MLP) and the multi-phase sustainability transitions

Many PCPs are related with societal functions or services fulfilled by what has been called *socio-technical systems* (Geels, 2005). These systems are "(networks of) actors (individuals, firms, and other organizations, collective actors) and institutions (societal and technical norms, regulations, standards of good practice), as well as material artefacts and knowledge" (Markard et al., 2012, p. 956).

Geels (2005) states that actors rend the socio-technical system stable by aligning and linking their behaviours with material infrastructure. Actors are considered to follow certain rules or rules' systems. These rules may be *regulative*, in the form of regulations and laws (including incentives and disincentives), *normative* or related to values, rights and responsibilities, or *cognitive* rules, related to symbols and the meaning we attribute to objects and activities (ibidem). Both, material means, and actors' networks and practices are considered to co-evolve in the configuration of dynamically stable "institutionalized structures" called *socio-technical regimes*.

One of the main models used in transition studies is the Multi-Level Perspective (MLP) (Figure 23). The MLP has its origin in innovation and technology studies (Grin et al., 2011) where it has been used to explain path dependency and lock-in situations of established socio-technical systems around specific technologies (Loorbach et al., 2017). Also, it allows us to analyse the (possible) dynamics of socio-technical systems.

It is constituted of three levels (see Figure 23, left). The central level is the socio-technical regime. It is considered to be "a dominant and stable configuration in a societal system (...) [that] emerge out of historical transitions and develop path-dependently through processes of optimization and incremental innovation" (Loorbach et al., 2017, p. 605). Infrastructure investments, scale benefits, etc., co-evolve with rules (see above) configuring the path-dependence of the final lock-in of the system.

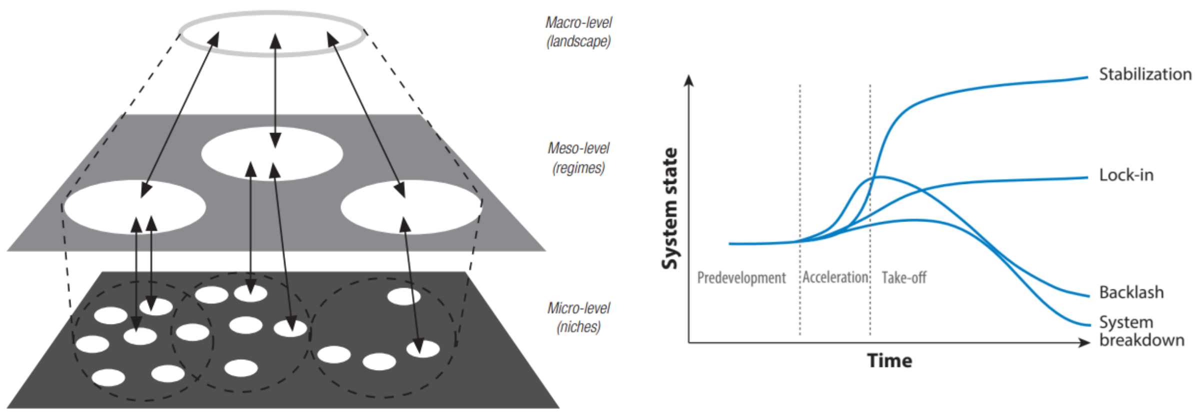

Figure 23: The Multi-Level Perspective (Loorbach 2007, p.20) (left); The multi-phase conception of transitions (Loorbach et al., 2017, p. 606) (right)

When achieving a stable configuration, the regime has high resilience and automatically inhibits any innovation that could alter its internal organization. Innovations are situated in the lowest level of the MLP: the micro-level or niches level. It is where the novelties are created, tested, and diffused if successful. These innovations may be new legislation, new technologies, new organizations, projects, or even ideas (Loorbach, 2007).

The highest level, the macro-level, also called the socio-technical landscape, contains aspects that influence the regime. These are "a set of deep structural trends external to the regime" (Geels, 2005, p. 78) related to social values, political culture, the built environment, and the economic situation. The landscape constitutes therefore an external context in which regime and niche actors interact and practically cannot be influenced. Landscape dynamics may be of two types (ibidem): the more common slow changes (cultural, ideological or demographic, for instance) or relatively rapid and abrupt changes as in the context of a war or an economic crisis.

The MLP serves to analyse how the dynamics between the three levels regarding sustainability transitions works. In this context, sustainability transitions are defined as "long-term, multi-dimensional, and fundamental transformation processes through which established socio-technical systems shift to more sustainable modes of production and consumption" (Markard et al., 2012, p. 956). These transformation processes "structurally alter the culture, structure and practices of a societal system" (Loorbach, 2007, p. 17).

The Multi-level phase model (see Figure 23, right) complements the MLP analysis as regards the transition dynamics. From this perspective, every transition has first a pre-development stage, in which novelties as seeds of change emerge at the niche level, challenging the regime. If innovations are diffused, change will accelerate. Then, if changes occur at the regime level and if novelties are aligned with the landscape configuration, a period of rapid development (take-off) may follow. Finally, a regime shift may occur through the stabilization of the new configuration.

In transition research, MLP and the multi-phases approach form "a sound and adequate heuristic framework to describe and explain the complex dynamics of societal transformations" (Loorbach, 2007)[33].

3.5.3.2 Transition Management

As mentioned above, the transitions research field includes the efforts to change current PCPs, under a normative perspective. In this context, new governance approaches were developed aiming at developing transition policies in areas such as

[33] The MLP has been the source of several critics, compiled for example by Geels (2005). As Loorbach (2007, p. 22) states, "any model to analyse societal systems is subjective (...) [A]ny analysis of a system is arbitrary and only valid as long as it is supported or recognized by actors that operate within it".

energy, water supply, and transport. One of these approaches is Transition Management (TM).

Loorbach and Rotmans (2010) situate the origin of TM in the Dutch 2001's National Environmental Policy Plan[34]. This Plan was guided by the idea that the management of transitions required, among other aspects (ibidem): to deal with uncertainties (e.g. through the use of scenarios), to stimulate knowledge and technological change paying attention to all relevant actors, and to have a long-term horizon and use-it to design short-term policies. Moreover, these general ideas were already translated into an operational model for its implementation, which is known as transition management cycle (Figure 24).

This cycle consists of the following steps (ibidem): 1) problem structuring, establishment of the transition arena and envisioning (see below); 2) developing coalitions and a transition agenda; 3) carrying out transition experiments and mobilizing the resulting transition networks; 4) monitoring, evaluating, and learning from the transition experiments and adjust the vision, agenda and coalitions, upon these results.

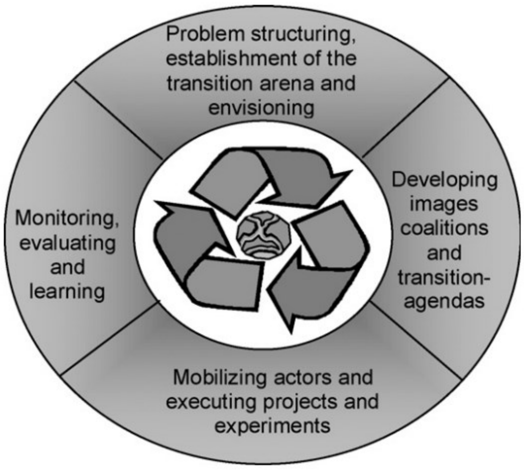

Figure 24: Transition Management cycle. Source: (Loorbach and Rotmans, 2010, p. 238)

The transition arena in TM is like the agora of Figure 22. Loorbach (2007, p. 151) defines the transition arena as a "protected environment" where "innovative and

[34] Much of the development of the Sustainability Transitions field is related to the Dutch government. Grin (2016) affirms that the Dutch Knowledge Network on System Innovations and Transitions (KSI, 2005–2010), major nationally funded research programme, was key for the development of Transition studies. The program "comprised eighty-five researchers, including thirty-eight PhD students, at eight Dutch universities and at TNO, a Dutch Great Technological Institute (GTI); they collaborated with some 750 transition practitioners in several dozen transition projects" (ibidem, p. 106).

visionary actors" can be brought together. In this space, "a new discourse can be developed. This new discourse involves a shared definition of a sustainability problem and a new solution of or vision on the problem"[35].

3.5.3.3 Transition experiments or real-world laboratories (living-labs)

An important aspect of the TM are the urban experiments or living-labs. These are defined as "real-life developments of drastically alternative ways of working and/or thinking, fitting into envisaged new system approaches" (Nevens et al., 2013, p. 114). They are part of the TM dynamic (Figure 25), helping to link the established vision with potential actions that could enable take-off and acceleration phases (ibidem).

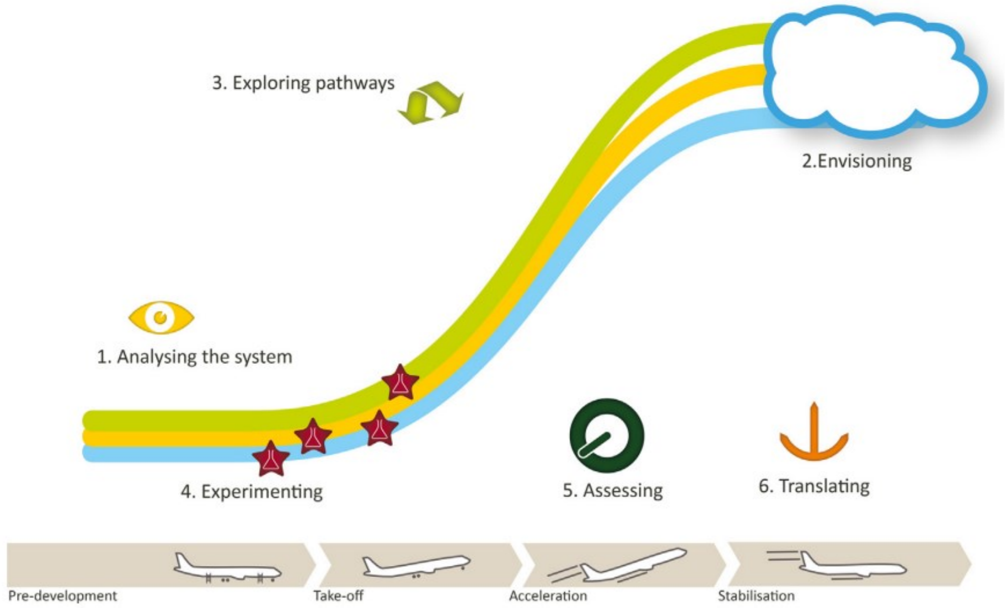

Figure 25: Steps and activities of TM. Source: Nevens et al.(2013, p. 114) based on Laes et al. (2014)

[35] For a fully description of the phase of the arena development, see Loorbach (2007), Chapter 6.

4

WM in Argentina and the Buenos Aires province

In this chapter, we first summarize some basic information about Argentina (section 4.1) and then we analyse the environmental and waste management legislation at the national level (section 4.2) and the same legislation for the Buenos Aires province in particular (section 4.3).

4.1 Basic characteristics of Argentina

Argentina is a federal country of 45.376.763 inhabitants (INDEC, 2020), comprising 23 provinces and the Autonomous City of Buenos Aires, the federal capital of the country. Article 1 of the Constitution states that the Argentine Nation adopts the federal republican representative form of government.

The Constitution states that Provinces "hold all the power not delegated by this Constitution to the federal Government" (Art. 121). They elect their authorities (Art. 122), had their own Constitutions (Art. 123) and are responsible for the control of the natural resources existing in their territory (Art. 124).

Population density vary widely between provinces, and between them and the City of Buenos Aires (see Figure 26 b). The most populated province of Argentina is Buenos Aires indeed. It comprises 135 municipalities for a total surface of 307,571 km². However, 63.4% of its population concentrates in the 24 municipalities forming the *Conurbano*, that is, the region which surrounds the City of Buenos Aires. Together they form the *Gran Buenos Aires*, a ~15 million people megacity. The rest of the province, which is called the *interior*, is mostly composed of small and middle-sized cities with a low density population.

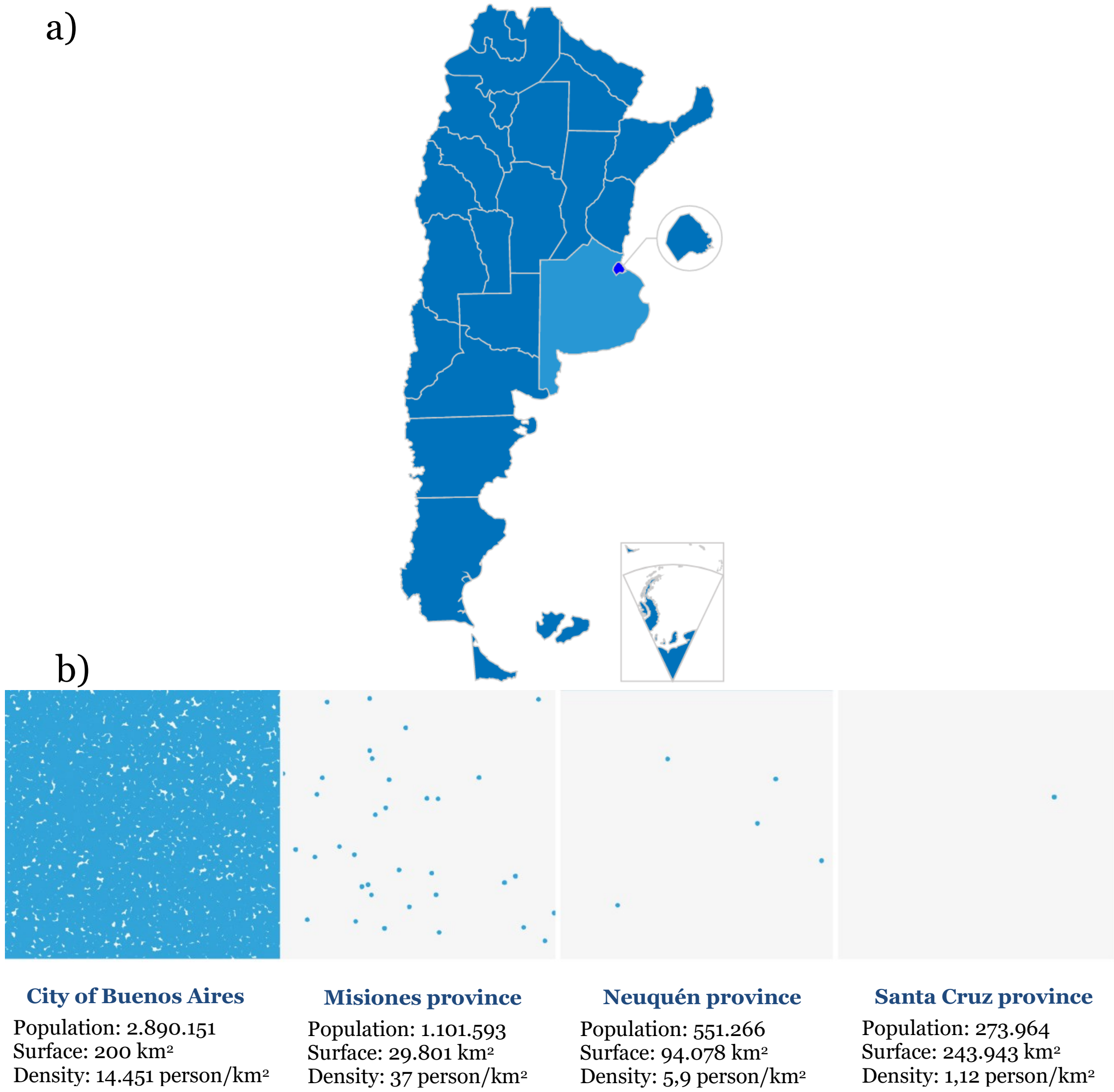

Figure 26: a) Map of Argentina. In light blue, the Province of Buenos Aires; in the circle, the detail of the Autonomous City of Buenos Aires. b) Comparison of population densities between different provinces and Buenos Aires city. Sources: a) www.argentina.gob.ar; b) Gregori (2017)

The total surface of the country is 3.761.274 km^2. Its latitudinal extension, between approximately 22° and 55° S, results in great climatic diversity. It ranges from the tropical climates of the Chaco, Tucumano-Orana and Misiones ecoregions, to the cold climates of the south (IGN, 2020). On the other hand, except in the Northwest, it enjoys a mainly oceanic climate because they form, together with Chile, a peninsula that narrows down southwards between the Atlantic and Pacific oceans (ibidem).

Rubio et al. (2019) highlight that Argentina owns some of the most fertile soils in the world. This is especially the case in the Pampean Region. Until recently, agriculture production in this region relied on natural soil fertility, without the addition of fertilizers, with negative effects on the soil nutrient balance (Alvarez et al., 2018; Lavado, 2019). These characteristics, together with the availability of metals and oil in the Andes Cordillera, shaped the recent biophysical performance of Argentina (Manrique et al., 2013).

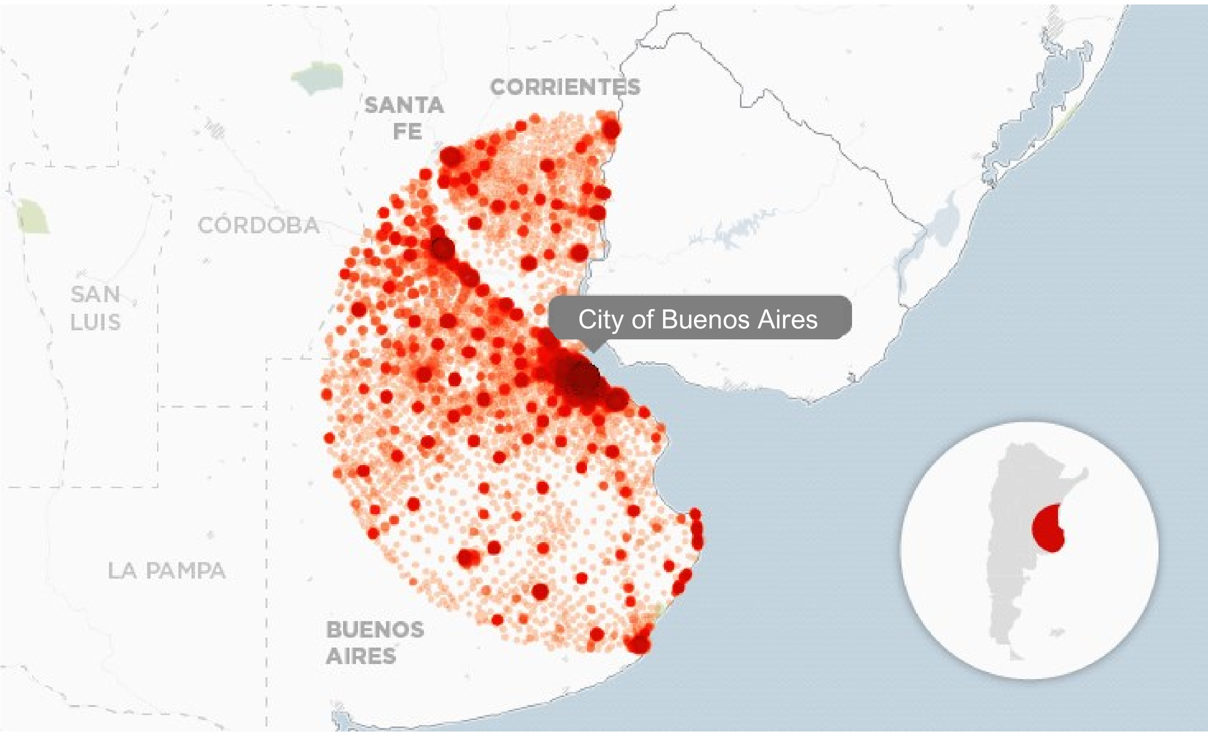

Figure 27: An analysis of the population density in a 400 km radius from the City of Buenos Aires, where half of the population of Argentina resides. Source: Gregori (2017)

4.2 Environmental regulation in Argentina

In Argentina, the constitutional reform of 1994 incorporated the right of all citizens to enjoy a healthy, balanced environment suitable for human development. At the same time, it established that it is up to the national government to enact the norms defining the "minimum requirements of environmental protection" for all the territory, giving the provinces the power to complement these norms. These “minimum standards” or “minimum budgets” are therefore the minimum bases or thresholds of protection that are in force throughout Argentina without the need for express recognition by local authorities (Taborda, 2008).

However, a recent report of the Ministry of the Environment and Sustainable Development (MinESD, 2019) signals that “the current waste regulatory system is outdated in light of the 1994 constitutional reform that recognizes the Minimum Budget laws as the tool to regulate the environmental issues at the national level” (p. 3).

Indeed, some laws enacted at the national level before the constitutional reform still regulate waste-related aspects. Some of them needed their endorsement by each province, which has not been the case for all of them (see Figure 28). On the other hand, some relevant aspects are still unregulated through minimal standards (ibidem), such as the Extended Producer Responsibility (EPR) as well as all the regulations related with the Universal Generation Special Waste [36].

The General Law on the Environment (N° 25.675/02) establishes the minimum budgets for "the achievement of a sustainable and adequate management of the environment, the preservation and protection of biological diversity, and the implementation of sustainable development" (Art. 1). It defines some principles valid to all environmental regulations, including those of[37]:

- *Coherence*, which establishes that provincial and municipal legislation related to the environment must align with the principles and norms established in the 25.675/02 Law
- *Prevention*, which indicates that causes and sources of environmental problems will be addressed as a priority and in an integrated manner.
- *Responsibility*, which defines that the generator of current or future degrading effects on the environment is responsible for the costs of preventive and corrective actions

Besides, the law defines general guidelines such as citizen participation, open access to environmental information, and environmental education.

[36] Resolution 522 - E/2016 of the Ministry of Environment and Sustainable Development establishes the "objectives, definitions and guidelines for the development of a national strategy for the Sustainable Management of Universally Generated Special Waste (UGSW)". These are defined as "any waste whose generation results from mass consumption and that, due to its environmental consequences or dangerous potential, require an environmentally appropriate and differentiated management from other waste" (Art. 3.a). Examples of UGSW are used tyres, WEEE, pesticide containers, mineral oils, paintings and asphalt membranes.

[37] The full list also includes the precautionary principle and the principles of intergenerational equity, progressivity, subsidiarity, sustainability, solidarity, and cooperation.

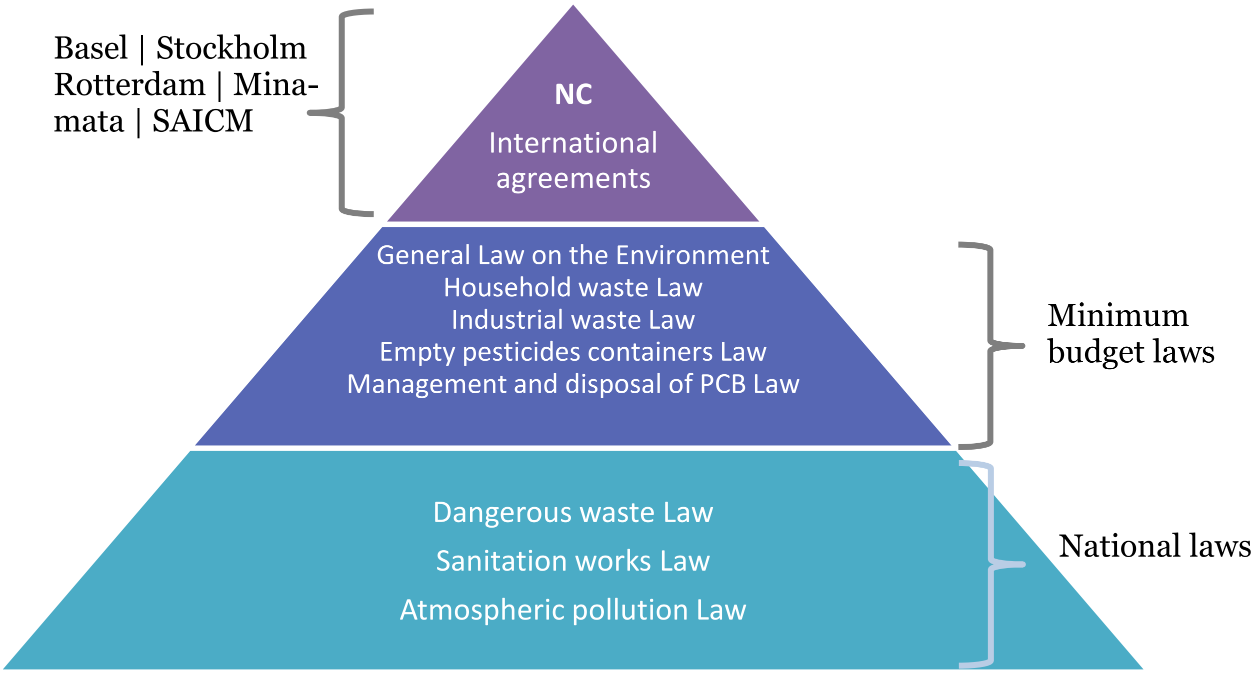

Figure 28: Structure of the waste regulatory system of Argentina. Source: MinESD (2019, p. 3)

4.3 Waste management in the national and provincial (Buenos Aires) legislation

In Argentina, National Law 25,916 of minimal standards on "Household Waste Management"[38] defines the integrated management of MSW as the combination of complementary and interdependent activities allowing for the management of household solid waste with the aim of protecting the environment and the life quality of people. Replicating the view of Tchobanoglous et al. (1994, 1982), the law then states that the "integrated household solid waste management" includes the phases of generation, initial disposal, collection, transfer, transportation, treatment, and final disposal[39]. Indeed, the chapters of the Law are organized on the basis of these steps.

In Buenos Aires, Provincial Law 13592/06, called "of integrated waste management", complement National Law 25.916. Its Art. 2 defines the "Integrated Management of Urban Solid Waste" as the "set of operations intended to give the waste produced in an area *an appropriate destination and treatment* in an *environmentally sustainable, technically, and economically feasible, and socially acceptable manner*" (we

[38] Although the title of the Law refers to household waste, Article 1 of this Law clarifies that it can be "of residential, commercial, healthcare, sanitary, industrial or in,stitutional origin, with the exception of the one regulated by specific norms".
[39] National Law 25.916 defines "final disposal" as "all the operations aimed at achieving permanent disposal of household waste, as well as unavoidable rejection fractions resulting from the treatment methods adopted". Recycling is included as a treatment.

highlight). Then, replicating the national law, it adds: "The integrated management includes the following stages: generation, initial disposal, collection, transport, storage, transfer plant, treatment and/or processing and final disposal".

The law focuses on finding an appropriate destination and treatment of waste. Its definitions are rather general and do not indicate how the ISWM should be implemented. Thus, several questions arise: 1) What is meant by "an adequate destination and treatment"? 2) What is meant by "environmentally sustainable”? How is it determined? Who should/can evaluate this? 3) What does "economic feasibility" mean in the context of a public service or a fundamental right such as waste management? 4) What is supposed to be acceptable to society and how is it determined? Furthermore, is what is socially acceptable in Tandil city also acceptable in other cities of the province?

These basic questions cannot be answered unilaterally by local authorities, even if they are ultimately responsible for carrying out the operational phases of the waste management. Indeed, as we saw in the previous chapter, this type of questions are characterized by a high uncertainty and high decisions stakes, requiring participative and transdisciplinary work.

4.3.1 Beyond the waste management phases: some generalities and some inconsistencies of the provincial waste management law

Both the national and the provincial laws, which constitute the minimum standard of action, include, in addition to the stages and that general premise of "sustainability", some general guidelines about the MSW management. The provincial law also defines some very concrete obligations for cities.

National Law 25.916 (Art. 4°) includes as its main objectives:

- To minimize the amount of waste destined for final disposal
- To promote the recovery of waste
- To minimize the negative impacts at different stages

On the other hand, Law 13.592/06, in Art. 3 and 4, includes the following (we summarize):

- 3R: reduce; reuse; recycle (Art. 3.3, 3.5 and 3.6 and Art. 4.2)

- Promotion of source separation (Art. 4.1)

- Promotion of the inclusive recycling (Art. 3.10)

- Citizen participation (Art. 3.11)

- Environmental education (Art. 4.3)

- The principle of “responsibility of the originator” (Art. 3.4)

For some objectives, such as environmental education or tax schemes, the law commits the provincial environmental authority to give advice to and to support the municipalities.

The only quantitative goal of the law is related to the objective "to minimize the amount of waste destined to final disposal". To achieve this, however, the 3Rs offer very different paths. In minimization and reuse, the amount of waste generated per inhabitant is lowered. Recycling, on the other hand, does not imply reducing the amount of waste generated per inhabitant but rather diverting it from final disposal and re-entering it into the production cycle.

In the text of Law 13,592, however, in what seems to be a major conceptual error, the minimization of generation and minimization of final disposal are taken as equivalents. Art. 4.2 indicates that one of the pillars of environmental policy in terms of MSW management should be "the minimization of waste generation, in accordance with the goals established in this Law and its regulations".

But the goal established by the Law for the municipalities is the following (Art. 6):

- To reach, within 5 years, “a 30% reduction of the total amount of waste destined to final disposal" with a progression of 10% reduction for the 2nd year, 20% for the 3rd year and 30% for the 5th year.

This progression should start after the approval (by the provincial environmental authority) of the Preliminary Basic Program (PBP) of IWM that each municipality had to present within the six months after the Law came into force, or, otherwise, after the approval of the final IWM Program (IWMP). Besides, the Law established general guidelines for organizing specific actions for those five years, as shown in Figure 29.

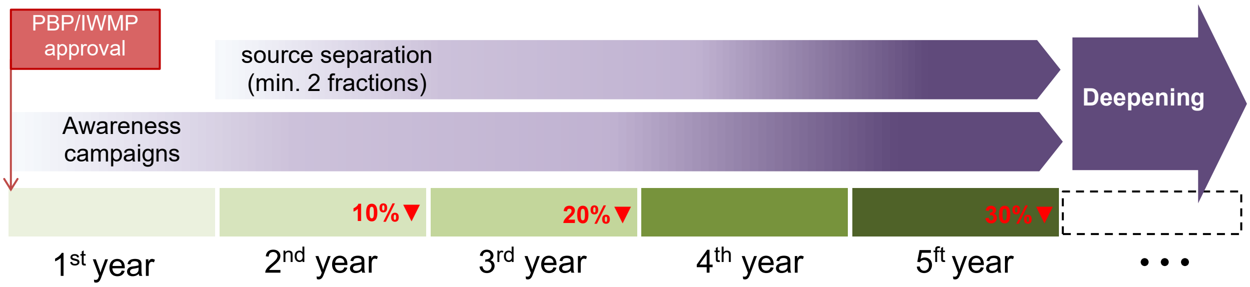

Figure 29: Action program established by Law 13592/06 for all the municipalities of Buenos Aires province. Source: the author

The law is ambiguous regarding the interpretation of these reduction goals and its Regulatory Decree does not give further details. If we consider "all waste destined to final disposal", we must assume that the reduction targets refer to the annual total of waste sent to final disposal in year zero (immediately prior to the presentation of the PBP/IWMP) and the indicator to be taken into account is t/year of final disposal.

Let´s take the case of a city of 25,000 inhabitants generating 1 kg/per/day waste that, when presenting the PBP/IWMP, sends 100% of the waste generated to final disposal; in addition to the 30% reduction required by the law, the reduction must also compensate for the natural increase of waste generation due to population growth (see Figure 30).

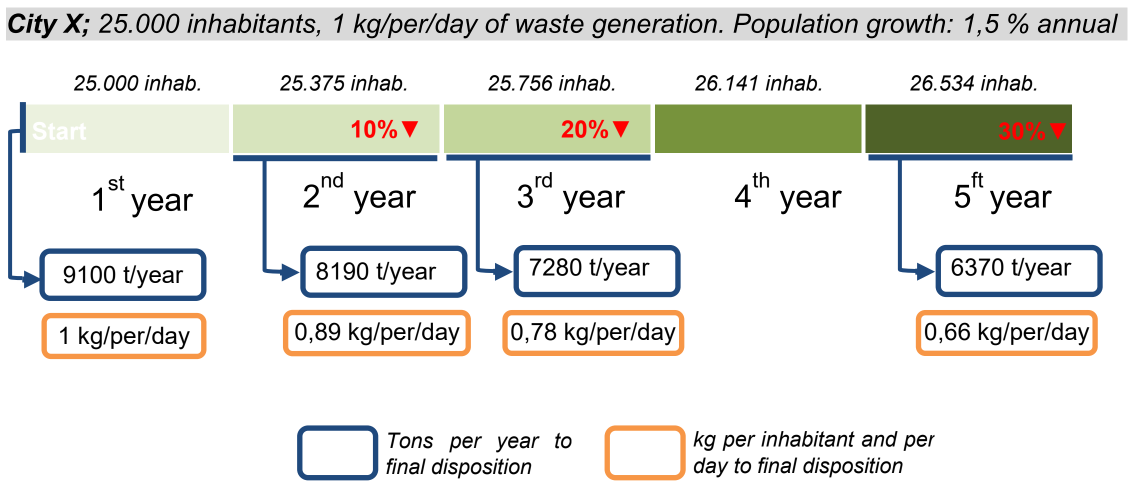

Figure 30: Example of compliance with the law 13592/06 for a city of 25,000 inhabitants. Source: the author

This means that the reduction to be achieved per capita is greater than 30% (around 34%). Given the lack of precision in the law, this reduction could be achieved through the reduction of waste generation or the increase of recycling, or a combination of both.

In the first case, achieving such a reduction would mean that profound changes are promoted in the production and consumption system, which involves the local, regional, national and probably the international levels (Lenzen and Peters, 2010). Regarding the second possibility, it is worth noting that the goals of the law are practically impossible to achieve without attacking the organic fraction. Typically, our municipalities have 50% organic matter in waste and approximately 20% non-recoverable waste (The World Bank, 2015). Of the recoverable waste, much of it is only recoverable in theory, since it is currently not recycled anywhere (for example, extruded polystyrene). Therefore, combining the two –a reduction of waste generation and an increase of recycling- seems to be the only way to achieve the goals.

In this regard, the Law also seems contradictory. One of the hallmarks of the Law is its promotion of regionalization in the treatment of waste (Art. 5.2). However, given the concrete possibility and convenience of treating organic waste locally, this point does not seem to be very appropriate for a 307,571 km^2 province with 135 municipalities.

The text of the law and its regulatory decree are neither clear about what happens if a city has had a significant level of recycling or has reduced waste generation before the enactment of the Law.

4.3.2 Waste pickers in legislation

Both National Law 25.916 and Provincial Law 13.592 recognize the role of waste pickers. In the first case, Art. 25, which defines the functions of its application authority, affirms that one of these functions should be "to promote measures that consider the integration of informal recovery circuits" (Art. 25 c). In the second case, the law first includes as one of its principles "the economic use of waste, aiming at the generation of employment in optimal health conditions, especially considering the situation of informal garbage workers" (sic)[40]. Also, when the Law defines the characteristics of the IWM Plans to be presented by municipalities (Art. 6), it explicitly states: "[t]hese plans should account for the existence of informal collection and recovery circuits in order to incorporate them into the integrated management system".

[40] Surprisingly, the law refers to *basura* (garbage) and not to *residuos* (waste). Even if both terms are synonyms, *basura* in Spanish or garbage, is related with the non-recoverable fraction of waste.

4.4 Conclusion: The failure of the waste regulation, an oversimplification of WM?

Despite the existing laws, the waste management reality in Buenos Aires province and Argentina is in general poor. According to the recent Plan for the Eradication of Open Dumps, there are 5000 open dumps in Argentina (Ministry of the Environment, 2020). This means that, in average, Argentina has more than two open dumps per municipality. Also, the Plan highlights that most of them are formal; in fact, they are the official final disposal method for most municipalities.

Regarding Buenos Aires province, only 90 of the 135 municipalities of the province had presented a PBP or an IWMP in 2019 (OPDS 2019). Furthermore, there were only 13 landfills approved by the environmental authority (OPDS) and 2 under construction in the province interior. We can see, then, that most municipalities are disposing their MSW in both controlled and uncontrolled open-air dumps (ibidem).

There is no data regarding the reduction of final disposal ordered by the law. Given the absence of more basic issues such as a safe waste disposal in most cities and the reality of those that had a sanitary landfill (like Tandil, see next Chapter), we can presume that the goals of the law were not met.

Several reasons account for these poor results. Leaving aside explanations related to a "cultural" lack of attachment to regulations, which in our opinion are simplistic and unhelpful, one of the causes behind this situation may be the approach of waste management underlying the legislation (the TWM), which oversimplifies the waste management issue. In Buenos Aires province, the ambitious targets of the Law and the lack of support from the provincial environmental authority could have annulated any effort of Municipalities to go forward in its accomplishment. We do not know who nor how these objectives were defined, but we know for sure that city mayors were not part of the process.

On the other hand, even if waste management is operationalized at the local level, cities may not have enough structural power to influence waste generation. Waste generation may be viewed as an emergent property of a complex system involving the local, regional, national, and international level. A coordinated action is therefore needed, but the legislation is ill suited for this.

Finally, the integration of waste pickers is not a trivial subject. Municipalities may be even less prepared for dealing with this social issue than with treatment technologies. We address this subject in Chapter 11.

5

Tandil city and the MSW issue

In this Chapter we present a baseline of waste management in Tandil, the city of our study case. After a characterization of the city regarding geographic, demographic, and infrastructural aspects in section 5.1, we present a baseline of the waste management system in section 5.2.

5.1 Characterization of Tandil city

Tandil city is located at the south-centre of Buenos Aires province. It was founded in 1823 when the so-called Independence Fort was put up between the two water streams crossing the city (Figure 31). This fort served as headquarters to fight against and finally exterminate the native population of this region and constituted the basis of the future urban development of the city (Fernández Equiza, 2017).

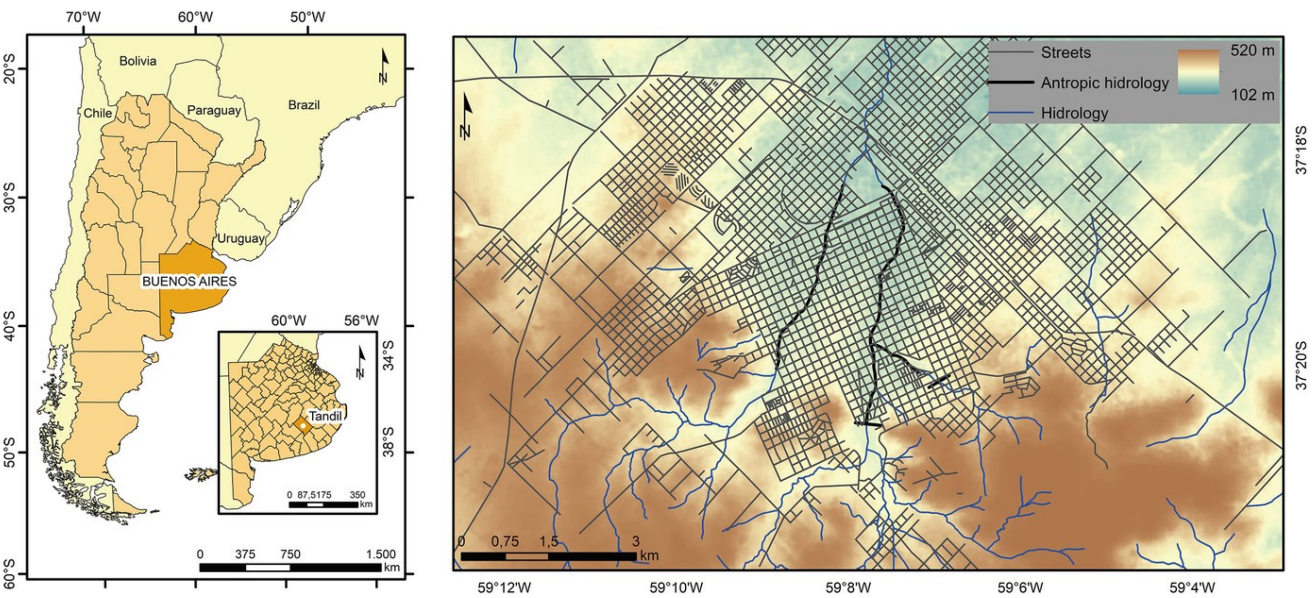

Figure 31: Tandil city. Location and elevation map. Source: Picone and Campo (2019). Reproduced with permission.

The climate is continental template, with an annual mean temperature of 13,4 °C and 855,4 mm of annual mean precipitation (Picone, 2012). The annual temperature mean is 14,5°C (Figure 32).

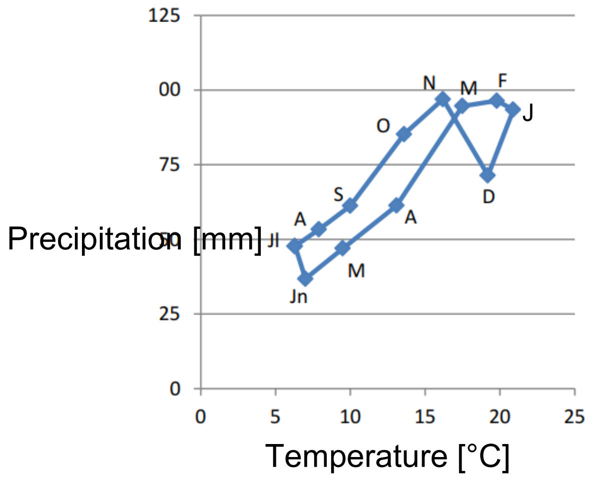

Figure 32: Temperature and precipitation graph for Tandil (2001-2010). Source: modified from Picone (2014)

The city is located at the northern side of the central area of the Tandilia range system (see also Figure 33). This location constrained the possibilities for the city to grow to the south and the west but did not prevent it. Indeed, during the last decades, the city developed following an urban sprawl model (Bruegmann, 2001; Fernández and Ramos, 2013).

Figure 33: Tandil city. The high buildings are concentrated in the city centre. In the rest of the city residences corresponds mainly to individual households. A big pit corresponding to an abandoned quarry can be appreciated at the bottom. Credit photo: Tandil Municipality

The projections of the last census estimated, for 2019, a population of 137.922 inhabitants for Tandil County, out of which approximately 130.000 live in the head city (Tandil) and the rest in four surrounding towns.

The structure of the population in 2010, shown in Figure 34, is getting to a halt in its growth and has an aging tendency. The pyramid has a narrow base, which is surpassed by age spans between 5 and 34.

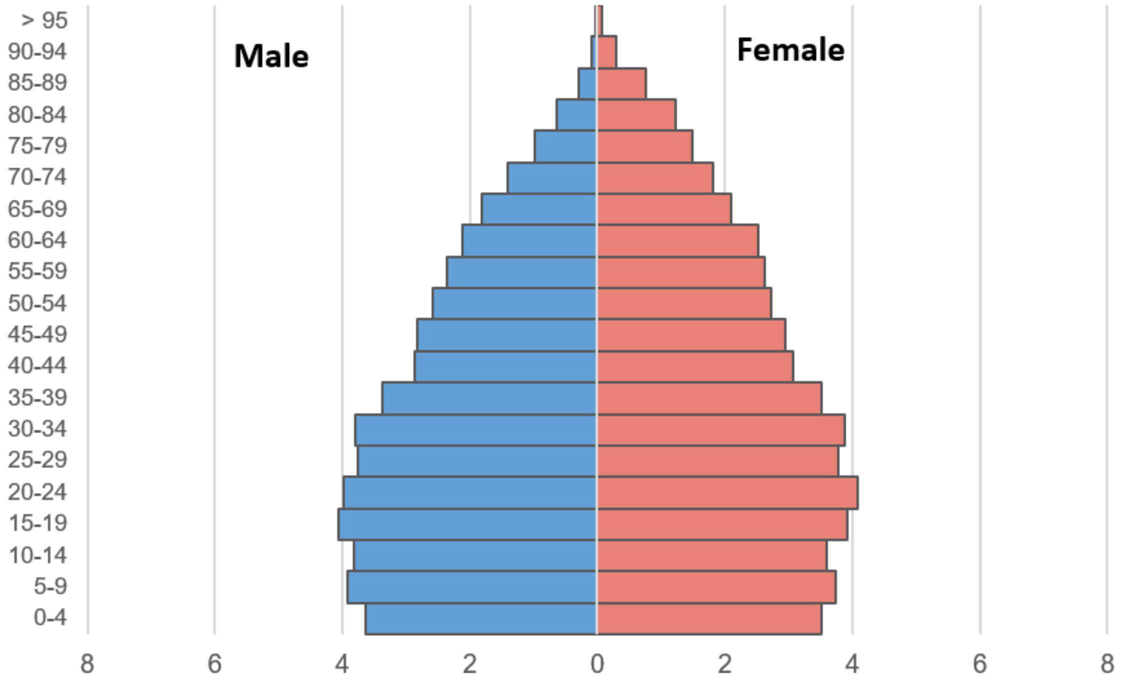

Figure 34: Population pyramid for Tandil city. The horizontal axe indicates the % of people for each age span and sex. Source: the author, with data of the last national census[41] (Edwin and INDEC, 2012)

In Tandil city, the average population density is 2100 pers/km² (Lan, 2011). However, significant differences exist between sectors in the centre of the city with high-density levels, sectors in urban consolidation with medium densities, and a semi-rural ring with very low densities (Figure 35). Inversely, when analysing the number of people per household in the centre of the city, we see that the density is very low.

In chapter 9 we make a stratification of households according to socioeconomic status in high, medium, and low. We can see that well-off households are located in the centre of the city and at the foothills, while the rest are mainly placed in the semi-circle formed by the north and east limits of the city. According to Linares et al. (Linares et al., 2016, p. 207) this is a socio-spatial segregation phenomenon by which “suitable land is

[41] A new census was planned for 2020 but it was cancelled due to the COVID-19 pandemic.

progressively occupied by high-income families, while the cheapest land is used for housing the low-income population".

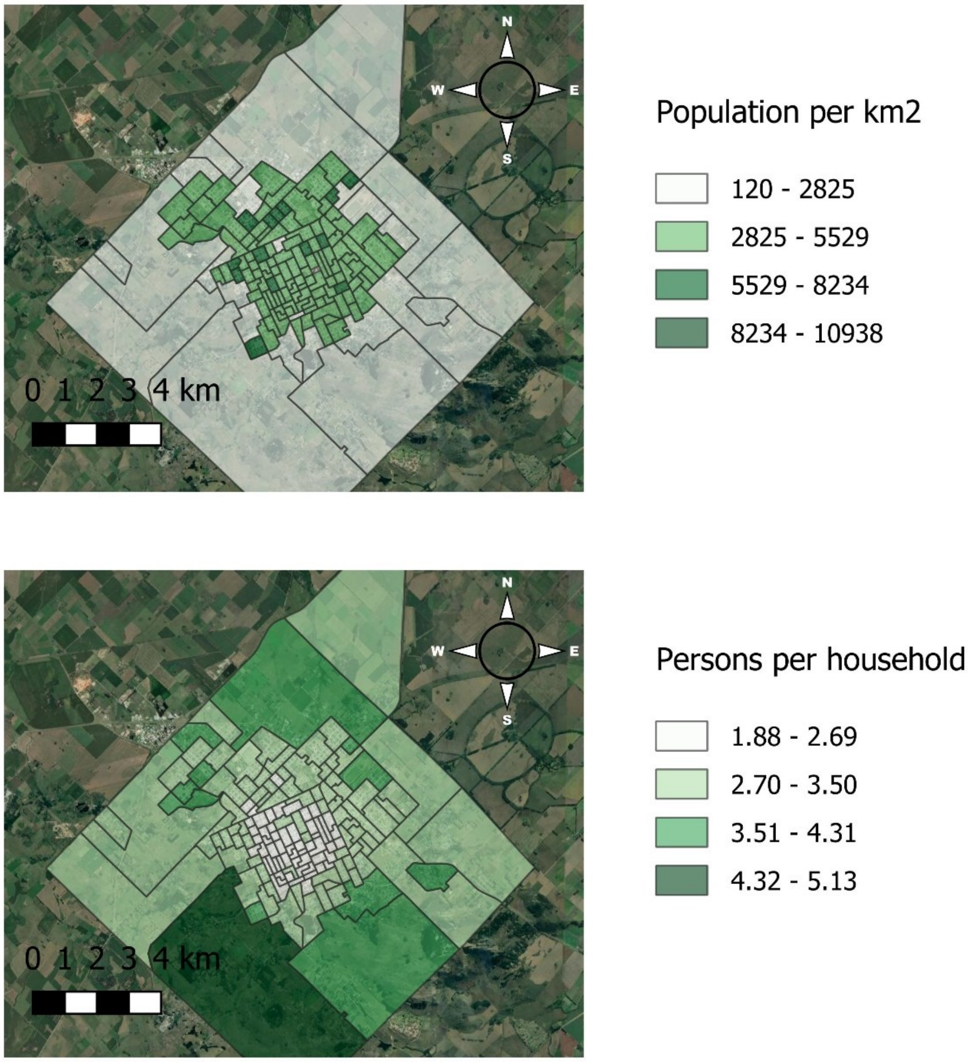

Figure 35: Population per square kilometre (above) and persons per household (bellow) in average per census blocks. Source: the author, with data of the last national census (Edwin and INDEC, 2012)

City infrastructure regarding tap water, sewage, and natural gas coverage is shown in Figure 36. Globally, tap water coverage is approximately 90% regarding the number of people, and only 60% for the sewage network (Cortelezzi et al., 2019). For natural gas, 80% of households access a network connexion (Edwin and INDEC, 2012).

These urban infrastructure deficiencies are related to both the diffuse development model of the city (Fernández and Ramos, 2013) and the city growth on rocky areas.

Regarding the former, the road infrastructure is proof of complications: only 30% of the total road length is paved.

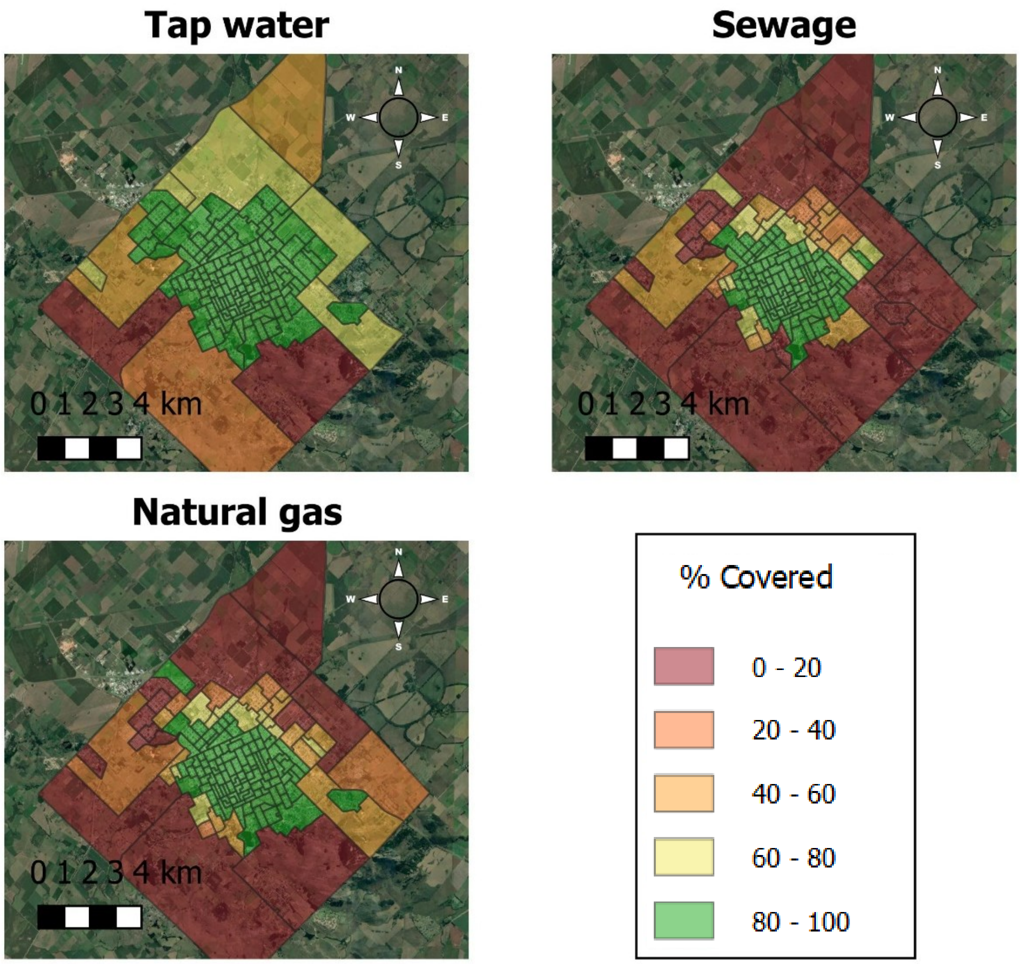

Figure 36: Public service coverages in percentage for each census block. Source: the author, with data of the last national census (Edwin and INDEC, 2012)

The economic structure of the city has changed over time. In the first half of the twentieth century, it was concentrated on primary activities associated with rock quarry exploitation and agriculture. In the second half of the twentieth century, it was succeeded by an industrial development focused on metallurgy and agri-food (Lan et al., 2010). In the last 30 years, the tertiary sector advanced greatly with the development of commerce, education, tourism, and finance services (Picone, 2014). Additionally, for the agriculture sector, Lan et al. (2010) signal that, during this period, GMO soybeans production displaced other traditional cultures.

The current city Mayor, Miguel Lunghi (1943), took office in 2003 representing the *Unión Cívica Radical* (UCR), a centrist social-liberal political party. In 2015, the UCR formed an alliance called *Cambiemos* with the right-liberal political party called *PRO*. Lunghi has been re-elected three times since 2003 and will be in office until 2023. For legal reasons, he cannot be re-elected once more (unless the province Constitution changes).

To summarize, it is worth mentioning that Tandil has been ranked third in the intermediate cities of Argentina regarding life quality (Velázquez, 2011). Yet, there are significant differences between the centre and the peripheric areas of the city in this respect (Linares et al., 2016).

5.2 Waste management baseline situation

The rapid expansion of the city put pressure on infrastructure and service demands, as mentioned above. This is also valid for waste management, principally in relation to waste collection (see below). However, the city is often considered an example because of its landfill (see below). In fact, a survey on satisfaction conducted by the local Statistics Direction in 2017 concluded that 90% of the population was satisfied with the quality and frequency of the WM collection service (Dirección de Estadística, 2017).

The municipality areas directly related to WM are two: the Services Office, responsible of waste collection, and the Environment Office, responsible of the recycling programs and educational activities. Both offices work under the Public Works Department.

5.2.1 Initial disposal and waste collection

MSW is initially disposed as mixed waste or separately by citizens at the sidewalks in metal baskets or similar to protect bags from stray dogs[42]. There is currently no containerization, except for some rural zones (Fuentes, 2015)[43]. However, it is usual to see municipal workers piling up waste every 100 m to speed up the collection phase.

Waste collection is made by means of compactor trucks (Figure 37; also Ch. 8 and 10 for further details). According to the Services Director (Fuentes, 2015), each truck should collect approximately 7-8 tons of waste, even if the capacity of the truck is bigger. This is to prevent the vehicles from an early ageing.

[42] In Ch. 8, 9, 10 and 11 we give further explanations of the WM system functioning.

[43] The local government made a pilot experience in a sector of the city, but it was cancelled because of wrong use by citizens (Fuentes, 2015).

In 2015, the service counted with 89 employees (drivers and collectors), out of which only 64 were active (Fuentes, 2015). The rest were off because of injury leaves.

Figure 37: A new compactor truck downloading waste in the sanitary landfill in 2016. Photo credit: the author

The coverage of the waste collection service is planned to be 100%, according to the Service Director (Fuentes, 2015). However, he admits that operative problems often prevent them from achieving this objective (ibidem). Also, offsets usually occur when new city zones get populated.

The number of collection routes have increased in the last decades from 7 day and 7 night tours in 1997 (García, 1999), to 8 day and 8 night tours in 2011 (Erreca et al., 2011) to 10 day and 11 night tours in 2015 (Fuentes, 2015)[44]. Day collection tours correspond to the peripheral areas, where routes are not paved and lighting is deficient (see Figure 38). Route limits and design are decided by truck drivers and operators. The Service Director only validates their decision. This arrangement aims at avoiding conflicts regarding imbalances in work loads of each team (ibidem).

[44] In 2019, 13 night and 16 day tours are reported (MdT, 2019). This increase in day tours can be associated with the rapid growth of the city in the peripheral zones.

Collection frequency is 6 days per week for the city centre (Monday-Saturday), 5 days per week in the rest of the dense urban zone (Monday-Friday) and three times per week in peripheral areas (usually Monday, Wednesday, and Friday).

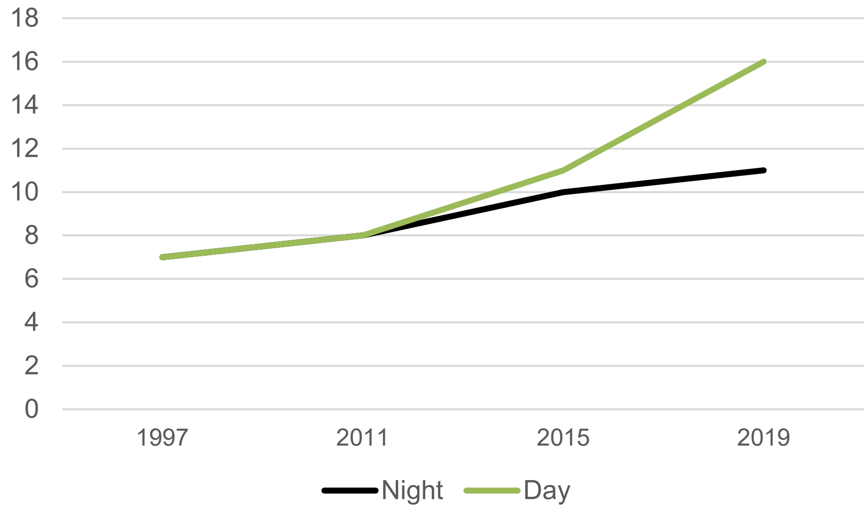

Figure 38: Evolution of the number of day and night waste collecting tours. Source: the author, based on García (1999), Erreca et al. (2011), Fuentes (2015) and MdT (2019)

5.2.2 Waste final disposal

Tandil sanitary landfill was inaugurated in 1998. Waste was openly dumped before. The landfill was operated by a private company first, and by a mixed public-private company later. Figure 39 shows the location and layout of the sanitary landfill, which was constructed next to the old open dump.

Figure 39: Location of the sanitary landfill (left). On the right: 1) the old open dump; 2) the first landfill (1998-2013); 3) the new sector (2104-2021?); 4) the leachate plant. Image source: Google Maps

The landfill has two development phases. The first (1998-2013), received approximately 500,000 tons of waste. The new sector, which is supposed to be operational until 2021, received, between 2014 and 2019 (November), 300,000 tons of waste. The reason for this growth is that waste disposal increases exponentially (Figure 40).

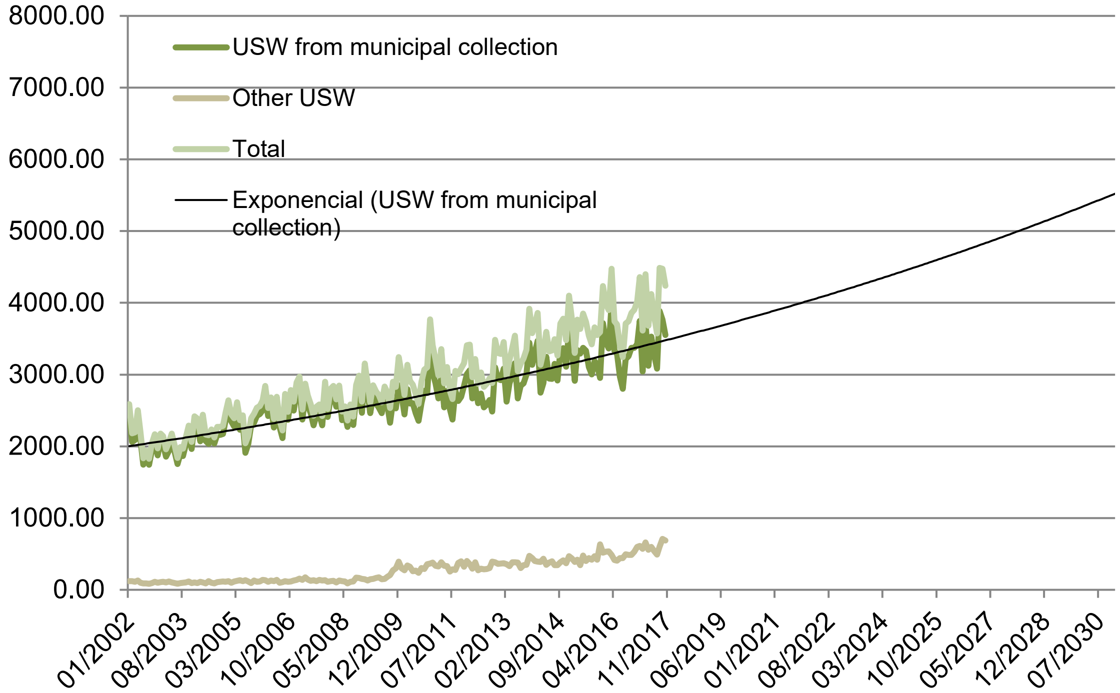

Figure 40: Monthly tons of USW arriving to the sanitary landfill and its projection. Source: the author with data provided by the landfill operator

The treatment plant of the landfill lixiviates did not work as planned. For the last decade, the only function of the plant has been to give a partial anaerobic and aerobic treatment to the leachate before its aspersion over the closed landfill modules. There is no declared release of effluents[45].

45 The level of leachate is, however, becoming unmanageable. When there is an excess of leachate, spontaneous holes in closed modules appear, that the operators call "ollaradas". In these holes, the leachate starts to cool because of its abundance and the internal pressure of the module. Trying to control this process, operators started to dig big holes on top of each module (Figure 39). However, in our last visit to the landfill in May 2019, we coincided with personnel from the Hydraulic Direction of the province who visited the landfill in response to a demand of effluent releasing made by the landfill operators.

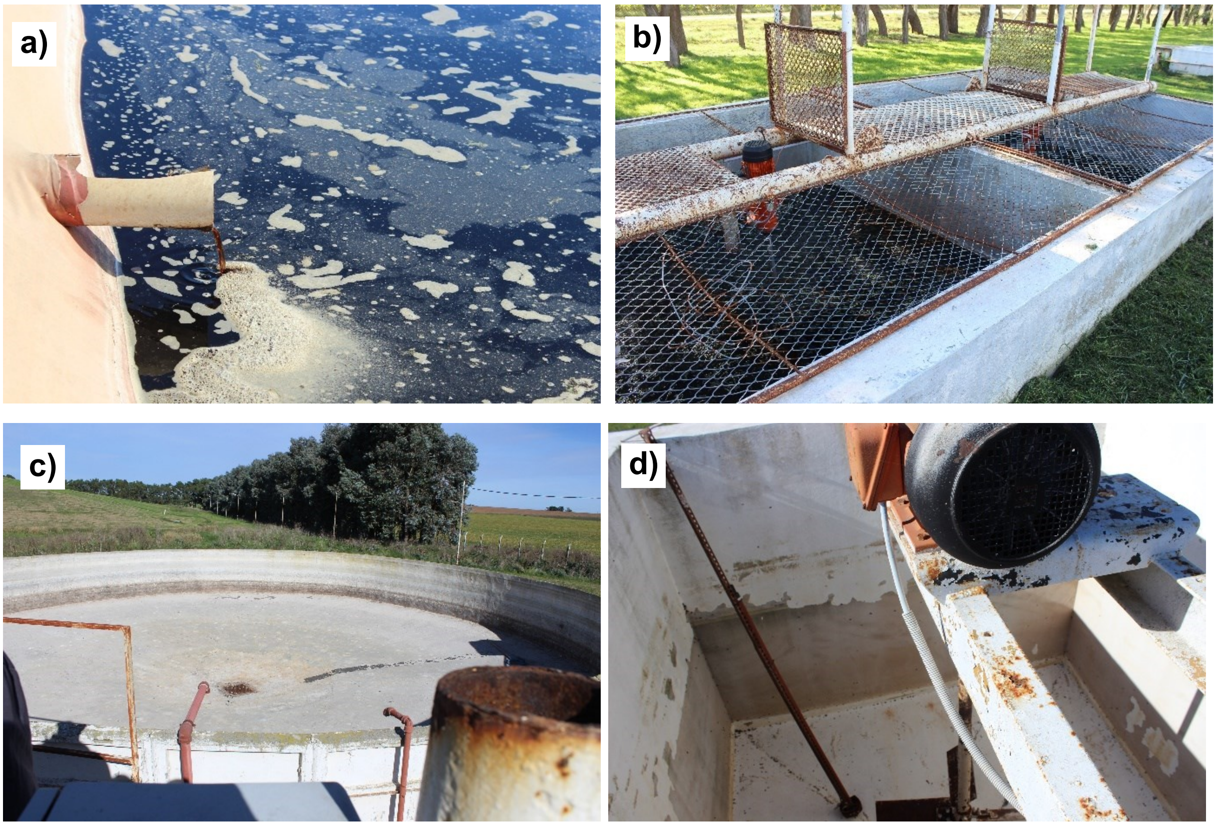

Figure 41: The leachate treatment plant. a) Imhof first tank; b) mechanical aeration; c) conditioning chamber (not used); d) conditioning tank/aeration (not used). Photo credit: the author

5.2.3 Waste recovery

The first formal and city-level recycling initiative dates back to 2009 and was led by a non-governmental organization (NGO). In the following years, other NGOs started similar programs, in some cases with the support (media attention, contacts) of the municipal Environment Office.

The informal recovery of materials, however, existed since long before. Registers of the work of waste pickers in the old open dump and the streets can be found since 1995 (García, 1999). Indeed, 77 waste pickers were censed between 1995 and 1996. Forty-seven worked on the streets and 30 of them at the disposal site[46]. For all of them, material recovery was the main source of revenue (ibidem). Although at the open dump some internal work schedule existed, the informal recycling sector (IRS) of Tandil was not organized.

[46] Some of them lived in the disposal site (García, 1999).

Figure 42: The old open dump. In the picture, at the bottom, we can identify a waste picker trolley and waste pickers working. Source: García (1999)

Under the pressure of the NGOs, the Municipality opened in 2015 a "Clean Point", i.e. a recoverable waste reception point, which operated as a transfer station with a temporary stock accumulation dynamic.

5.3 Local legislation and compliance of provincial and national legislation

Tandil city does not have a local ordinance to regulate waste management. Several project proposals were presented by NGOs (in 2014) and councillors (in 2008) but they are still waiting for treatment.

Provincial Law 13.592 is, therefore, the legislation in force. However, Tandil never presented the IWM Plan required by the Law (see previous Chapter) and, contrary the Law, when the Clean Points were launched, waste pickers were not considered part of the arrangement.

5.4 Conclusion: The context of this thesis

In 2014, when the landfill needed to be extended, the managing private company did not renew its contract and was relayed by the most important public-private company of Tandil: USICOM[47]. In this context, the local government announced, in June 2014,

[47] In fact, the owners changed, but the functioning of the landfill did not. They formed a joint-venture during 12 months to manage the relief but the person in charge of the landfill and the employees were the same before and after the transfer.

that they requested to USICOM a feasibility analysis for the installation of a mixed waste recycling facility (ABCHoy, 2014).

The project was intended to incorporate an MSW treatment plant "as modern as possible", in the words of the Mayor, in which "we will be all integrated, the private sector and the State" (El Eco de Tandil, 2014).

The waste issue in Tandil has gained momentum since then. To illustrate this, we analysed the number of articles containing the words "waste" and "recycling" in the most popular newspaper of Tandil (El Eco de Tandil)[48]. Results for the period 2008-2019 are shown in Figure 43.

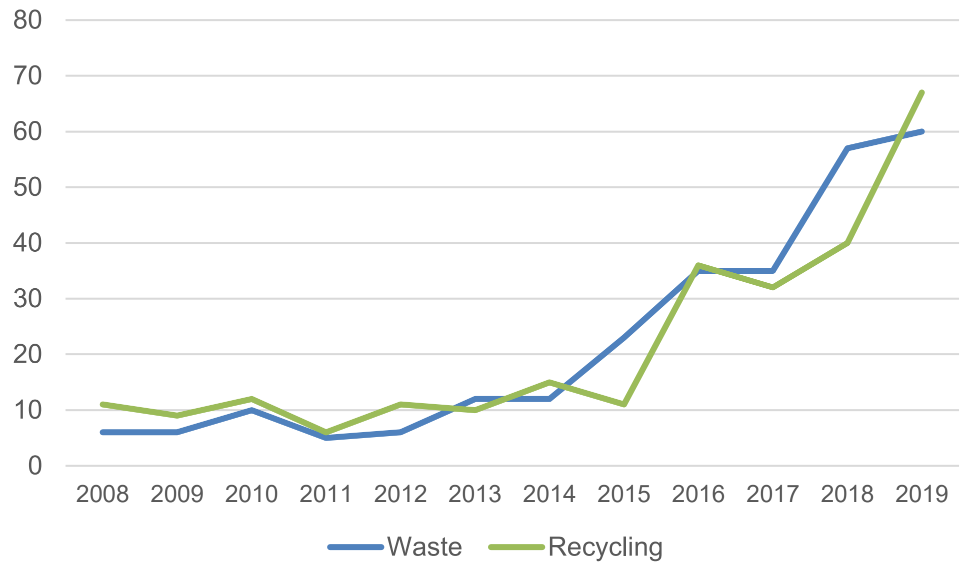

Figure 43: Occurrence frequencies of articles containing the words "waste" or "recycling" in the online version of the journal El Eco de Tandil. Source: the author upon data from Google Research Engine

This thesis was embedded in this process. In the next chapter we present our research questions and objectives.

[48] Results are based on the online version of the journal: www.eleco.com.ar

6

Research questions and objectives of the thesis

This thesis by articles addresses the issue of waste management in Tandil city. It is the result of five years of individual and collective work, which included theoretical reflection, fieldwork, and action research aimed at influencing the ongoing transformation process of the local waste management system, with a special concern about the waste pickers' situation.

The work we present here is part of a larger process, in which we adopted a transdisciplinary approach, which is described in Chapter 7.

6.1 General research questions

During the development of the thesis, important changes occurred both at the local and the national level, that affected our system under study. New actors and even new institutions emerged. New information available (in part as a result of our work) was used by actors in ways that reshaped the waste management landscape of Tandil.

Therefore, our research questions changed, evolved, some of them were deepened and others discarded. Also, new research questions appeared, and today we have probably more research questions than before the beginning of this process.

The research path we followed, therefore, was not linear but iterative. However, we can identify three basic research questions that guided the beginning of this thesis, and that correspond to the three types of research questions of a transdisciplinary project (section 3.4.1):

1. What is an adequate framework of integrated solid waste management (ISWM) for a city like Tandil (target knowledge)?
2. How is the current waste management system of Tandil functioning concerning this standard (system knowledge)?

3. What is/are the adequate/s approach/es and tool/s to guide/influence/transform the waste management system of a city like Tandil (transformation knowledge)?

The first and partially the third question were addressed at the beginning of the thesis when we analysed the state-of-the-art in the matter. Concerning the first question, our efforts were focused on experiences and models of waste management conceived for and implemented in developing countries. The results of this phase are included in Ch. 2 and reflected in the scientific articles (Ch. 9-11). Regarding the third question, we introduced the concept of complex and persistent problems (PCP) in cities and the epistemic and methodological challenges associated with them in Chapter 3. We also presented some approaches that we considered pertinent to deal with PCP. However, one of our main developments is related to the similarities between transdisciplinary approaches and the Latin American University Extension. Chapter 7 explores this aspect.

The evaluation of how the current waste management system of Tandil worked, the second question, was addressed at different moments of the thesis and in different ways. First, it was treated in the exploratory research phase, which included semi-structured interviews with key actors of the waste management system of Tandil, like the municipal Waste Collection Service Responsible, NGO's and civil associations' referents, the municipal Environmental Office Director, the biggest intermediary of Tandil, and others. This phase also comprised several visits to the local landfill, the Clean Points, and the civil associations' workplaces. Finally, we also made participative observation during our first project with waste pickers (see Ch. 8).

6.2 First article: aim and objectives

One of the main findings of the exploratory research phase was the absence of primary data, notably related to waste generation and recycling rates. As explained in the introduction of Ch. 9, this information is a fundamental input for waste management policy design (Christensen, 2011a; Sahimaa et al., 2015). Recycling rates are impossible to measure precisely if waste generation and composition are not well known (see also Ch. 10).

Thus, one of the first objectives of the thesis, shared with other researchers of the Environmental Research and Studies Centre (CINEA), was to perform an MSW characterization. For reasons that are explained in Ch. 9 and 10, we focused on waste generated in households. Our first article is the result of this work (Villalba et al., 2020; Chapter 9). It comprised the following specific objectives:

1a. To perform a stratified house-to-house characterization of waste under budget constraints
1b. To evaluate the quality of the obtained results and compare them with other studies
1c. To analyse the connexion between these results and local cultural habits

6.3 Second article: aim and objectives

As we explain in the second article of the thesis (Ch. 10), we used Material Flow Analysis from the beginning of our work to describe and understand how the waste system works. However, once we counted with the waste characterization data, we combined it with complementary information obtained in the exploratory phase and with secondary sources to calculate formal and informal recycling and performances indicators. In this article (Villalba, 2020a; Chapter 10), we also used the results of the MFA study to evaluate how performative the waste system is considering the drivers of the ISWM framework.

The specific objectives of the second article were:

2a. To apply the MFA approach to the waste management system (WMS) of Tandil city by incorporating measurement uncertainties
2b. To use this information to conceptualize and calculate the indicators needed to evaluate the recovery potential and current performance of strategies in place (formal and informal)
2c. To explore, on the basis of obtained results, ways to improve the WMS functioning, regarding the local legislation and the drivers of the ISWM

The final results of the use of MFA, including an uncertainty analysis, were completed in 2019. However, we presented the first rough estimations of this analysis to relevant actors well before, in 2017 (referenced to the year 2016). These preliminary results, which were very similar to those presented in the article, indicated that the Informal Recycling Sector (IRS) of Tandil recovered much more waste than the official Clean Points strategy. This information was used by waste pickers during its organization phase, to reinforce their demands to the local government.

6.4 Third article: aim and objectives

Our support for the inclusion and improvement of working and life conditions of the IRS of Tandil was motivated by different reasons. First, because we started our research working under the approach of the Latin American Extension (see Ch. 7), which, in its critical strand, advocates for concentrated efforts to solve problems of the most vulnerable groups of society. Second, because the framework of ISWM we adopted later (see Ch. 8) considered the inclusion of the IRS as a key component of the best waste management practices.

As we explain in our 3rd article, registers of the IRS of Tandil exist since 1996, but they have worked in the old municipal dumpsite since well before that year. However, until recently, they worked individually and subdued to intermediary selling conditions. During this thesis, we were part of and accompanied the organization process of the IRS of Tandil. Our support included actions which ranged from purely academic ones, as the generation of basic data that showed their relevance for the recovery of materials, to purely militant ones, like accompanying their public protest, to more institutionalized forms, like the writing with IRS referents of an ordinance project to regulate large waste generators through the *Mesa GIRSU*, a boundary organization we have coordinate since 2017.

All these actions were aimed to enhance IRS opportunities. However, the situation of the IRS of Tandil (and therefore our thesis) was marked by changes also at the national level. One of these changes was related to a very specific trait of the IRS sector in Argentina: its evolution as part of we call today the “popular economy”. In our 3rd article (Villalba, 2020b; Chapter 11) we focused on this situation.

Thus, the objectives of the last article were:

- 3a. to recap the recent evolution of the IRS as part of the “popular economy” in Argentina
- 3b. to evaluate, through the InteRa framework (Velis et al., 2012), how these changes, along with academic and civil society support actions, impacted on the IRS integration in Tandil

The third general research question, as we said above, was first addressed theoretically. In Ch. 3, we identified several approaches recognized as adequate to deal with complex and persistent problems. Regarding this aspect, again, the emergence of new institutions conditioned our work. At the initiative of a city councillor, a permanent round table to work on the integrated solid waste management of Tandil (Mesa GIRSU) was launched in 2016. The first participants of this Table asked the local university for a representative and we managed to be designed in this post and to become its coordinator.

Our efforts regarding the actions intended to address the waste management as a PCP were mainly canalized through this organization. In Ch. 8, we explain how the *Mesa GIRSU* can be viewed as a boundary organization in which we worked with different stakeholders under a transdisciplinary approach.

PART II

§ Transdisciplinary science in Tandil city: Empowering the Informal Recycling Sector through primary data generation, Material Flow Analysis and boundary organizations

7

Latin American Extension as transformative science

Before introducing the articles of the thesis, in this chapter we will present an action-oriented approach that is specific to the LAC Region: the Latin American University Extension (LAE). We argue that LAE is an institutionalized platform for the application of transdisciplinary research, at least in Argentina. In section 7.1 we present the origins of the movement and in section 7.2 its diffusion in Latin America. Section 7.3 explores the relation between the LAE and transdisciplinarity, while section 7.4 explains the current institutions of the LAE in the LAC region, with a detailed description of the Argentinean case.

7.1 The origin of LAE: The University Reform Movement (URM)

The roots of the LAE can be tracked back to the first decades of the last century in the Southern Cone countries, in the context of what is known as the University Reform Movement (URM) (Arocena and Sutz, 2005; Ciria and Sanguinetti, 1987; Díaz de Guijarro and Linares, 2018; Tünnermann Bernheim, 2000). The Latin American students of the reformist movement were influenced by the European university extension practices (Cano Menoni, 2017)[49]. However, they gave to this concept a renewed signification. Although specifically in Uruguay and Perú there are some early references to university extension, the origins of the URM are situated in Argentina and are related to the country's specific historic context.

In the late 19th and the early 20th century, Argentina was dominated by a powerful agro-exporter oligarchy (Ciria and Sanguinetti, 1987). Universities, in turn, were still

[49] The university extension movement in universities like Cambridge started in the 1860's and were focused in open teaching for those who could not attend the University (see for example Browning, 1887 and; Michelli and Giacomino, 2019). Also, influences of specific actors like don Rafael Altamira from the University of Oviedo are acknowledged (see Cano Menoni, 2017).

the reflection of old structures that the independence had not be able to modify (Tünnermann Bernheim, 2000, 1998). Only an elite had access to these higher institutions, which were focused on educating the professionals required by the economic system (Arocena and Sutz, 2005).

At the same time, immigration in Argentina boomed, which meant that the population quintuplicated between 1869 and 1914; half the children born in 1914 were immigrants' children (Ciria and Sanguinetti, 1987). Urbanization and internal migrations resulted in an urban population which doubled the rural one. The expansion of the railway and the creation of industries to satisfy construction and internal basic consumption needs such as flour, sugar, and textiles, characterized a new capitalist and industrial facet of the economy (Díaz de Guijarro and Linares, 2018). Urban concentration gave rise to the first trade unions in the late 19th century; eventually, a proletarian industrial population laid the foundation for the middle class of the most important cities (ibidem).

Changes occurred in the political context, too. The creation of the Socialist party, which in 1904 managed to have representatives in the National Congress, on the one hand, and the rise of an anarchist movement, on the other, resulted in a government open to more progressist political referents in an effort to avoid social conflicts (Ciria and Sanguinetti, 1987). This led to the universal, secret, and obligatory vote in 1912, which resulted in weaker conservative party government.

In this complex context, which also included tensions between the Justice and the Church, students from Universidad Nacional de Córdoba started a revolt in 1918 with the support of the incipient middle class and trade unions. This revolt was a turning point in the history of Latin American universities. The conflict started as a relatively trivial protest, related to a new requirement for class attendance, but soon it turned into a social protest where all the social disconformities were represented.

Figure 44: Protest by Universidad Nacional de Córdoba students in 1918. Photo credit: Museum of the University Reform – Universidad Nacional de Córdoba

After some months of riots which included the creation of the Córdoba University Federation (Ciria and Sanguinetti, 1987), the university was closed down by the authorities. Then, the students seized power and designated new authorities and faculty, after which they were arrested. The national government dictated the intervention of the university, which resulted in several riots between students and the police. Eventually however, the University Reform Movement was launched, and it achieved its first goal: the replacement of the old authorities.

7.2 The Liminal Manifesto and the dissemination of the URM in the LAC region

The Liminal Manifesto of 1918[50], the URM foundational document, was addressed to "the freemen of South America". As stated by Arocena and Sutz (2005, p. 574),

> *[t]heir Manifesto became the 'Marseillaise' of the URM, a movement that spread quickly. In every country of Latin America, including Brazil, students organized themselves, challenged the academic status quo, and obtained increasing support for their projects concerning the Reform of the University*

One of its most important demands was the *cogobierno*, that is, the autonomous direction of universities by its students, faculty and graduates. But the URM aspired to

[50] The Liminal Manifesto was written by Deodoro Roca, a young reformist lawyer.

more than that. They wanted to turn the university into an agent of social change (Arocena and Sutz, 2005).

The emphasis of the "social function" of the university, i.e. "the purpose of putting university knowledge at the service of society and making its problems a fundamental issue" (Tünnermann Bernheim, 2000, p. 3) was part of the Reform postulates from the start; it was, in fact, the Manifesto corollary (ibidem).

The essence of this social function was finally assigned to the Extension area, which was incorporated as the third mission of Latin American universities (ibidem).

The "third university mission" concept is present in many countries. However, the term is not used with the same meaning everywhere. Göransson and Brundenius (2012) present the results of the project UniDev, in which they explored how universities define their role in 12 different countries around the World. They showed that in almost all the countries under study (except for Uruguay, Cuba, and Vietnam), the scope of the third mission was narrowed to a technological transfer. Consequently, authors like Trencher et al. (2014, 2013), refer to something that is "beyond the third mission" when analysing the university function of "co-creation for sustainability" (understood in a similar way that the Extension concept; see Villalba, 2016).

Thus, the name "Extension" is inappropriate for understanding its objectives because its meaning differs from that of the European University Extension activities.

7.3 Extension models: from knowledge transfer to a new transdisciplinary mainstream

By the mid-20th century, the definition of Extension as a third university mission was well established in the region. In 1957, during the "First Latin American Conference on University Extension and Promotion of Culture", the definition of the concept adopted was as follows (quoted by Tünnermann Bernheim, 2000):

> *The university extension must be conceptualized by its nature, content, procedures and purposes, as follows: by its nature, the university extension is the mission and guiding function of the contemporary university, understood as an exercise of the university vocation. Regarding its content and procedure, the university extension is based on the set of philosophical, scientific, artistic and technical studies and activities, through which the problems, data*

and cultural values that exist in all social groups are auscultated, explored and collected from the social, national, and universal environment. For its purposes, the university extension must adopt, as fundamental purposes, to project the culture dynamically and in a coordinated manner and link the people with the university. In addition to these purposes, the university extension should seek to stimulate social development, raise the spiritual, intellectual, and technical level of the nation, proposing, impartially and objectively on behalf of the public opinion, the fundamental solutions to problems of general interest[51]

This definition, however, conceives the university as a means of transferring knowledge and culture to society in an univocal sense (Tünnermann Bernheim, 2000).

The work of Paulo Freire in educational theory, as well as the contributions of other sociologists and anthropologists, changed this conception of the University Extension in the 60's. In "Extension or communication?" (Freire, 1982 [1969]), in which Freire analyses the role of university agents in the context of the green revolution (Paddock, 1970; Pimentel, 1996) in Brazil, he starts its essay by criticizing the use of the term "extension" and questioning its symbolic and concrete translation into practice. Instead of a lineal extension of knowledge (referred to as the "banking model of education"), Freire proposes a dialogical conception of education: "The role of the educator is not to 'fill' the educate with 'knowledge', technical or otherwise. It is, rather, an attempt by both the educator and the educate to move towards a new way of thinking through the dialogical relationships between both. The flow is bidirectional" (Freire, 1982 [1969], p.123).

[51] My translation. The original quotation is: "La extensión universitaria debe ser conceptuada por su naturaleza, contenido, procedimientos y finalidades, de la siguiente manera: Por su naturaleza, la extensión universitaria es misión y función orientadora de la universidad contemporánea, entendida como ejercicio de la vocación universitaria. Por su contenido y procedimiento, la extensión universitaria se funda en el conjunto de estudios y actividades filosóficas, científicas, artísticas y técnicas, mediante el cual se auscultan, exploran y recogen del medio social, nacional y universal, los problemas, datos y valores culturales que existen en todos los grupos sociales. Por sus finalidades, la extensión universitaria debe proponerse, como fines fundamentales proyectar dinámica y coordinadamente la cultura y vincular a todo el pueblo con la universidad. Además de dichos fines, la extensión universitaria debe procurar estimular el desarrollo social, elevar el nivel espiritual, intelectual y técnico de la nación, proponiendo, imparcial y objetivamente ante la opinión pública, las soluciones fundamentales a los problemas de interés general"

Freire inspired many Marxist authors in the 70's and 80's which also nurtured the concept "Extension". One of the most important was Orlando Fals Borda from Colombia, who founded the methodology of Participatory Action-Research (PAR) with other colleagues in the 70's. The PAR approach is defined as an "experimental methodology" aiming at transforming the social reality in favour of the most vulnerable. The PAR "implies the acquisition of serious and reliable knowledge upon which to construct power, or countervailing power, for the poor, oppressed, and exploited groups and social classes -the grassroots- and for their authentic organizations and movements" (Fals-Borda and Rahman, 1991, p. 3)[52]. The PAR is also characterized by researchers directly engaged with the political agenda, something that, in the beginnings of the methodology, was known as the "militant research" concept (Bonilla et al., 1972 Ch. 3). It is moving "from the micro to the macro", according to Fals Borda and Rahman (1991, p. 6) "as if in a spiral", that PAR "acquires a political dimension" (ibidem). Regarding methodologies, Fals Borda and Rahman (pp. 8-9) mention: collective research, critical recovery of history, valuing and applying folk culture, and production and dissemination of new knowledge (in a non-traditional manner). Finally, the notion of *empowerment* is also key to the PAR because it is considered that "[p]eople cannot be liberated by a consciousness and knowledge other than their own" and, therefore, "it is absolutely essential that people develop their own endogenous consciousness-raising and knowledge generation" (p.16).

This line of thought led to a model of Extension that Tomassino and Cano Menoni (2016a) have called the *critical extension model*, which is based on Freire's approach. Its participants adopt a clear and explicit political position and share the purpose of transforming society through the extension practice. On the other extreme, they place the *traditional extension model*, which is mainly based on knowledge transfer and promotion of culture.

[52] This is because the "domination of the masses by the elites is rooted not only in the polarization of control over the means of material production but also over the means of knowledge production, including control over the social power to determine what is useful knowledge" (p. 14).

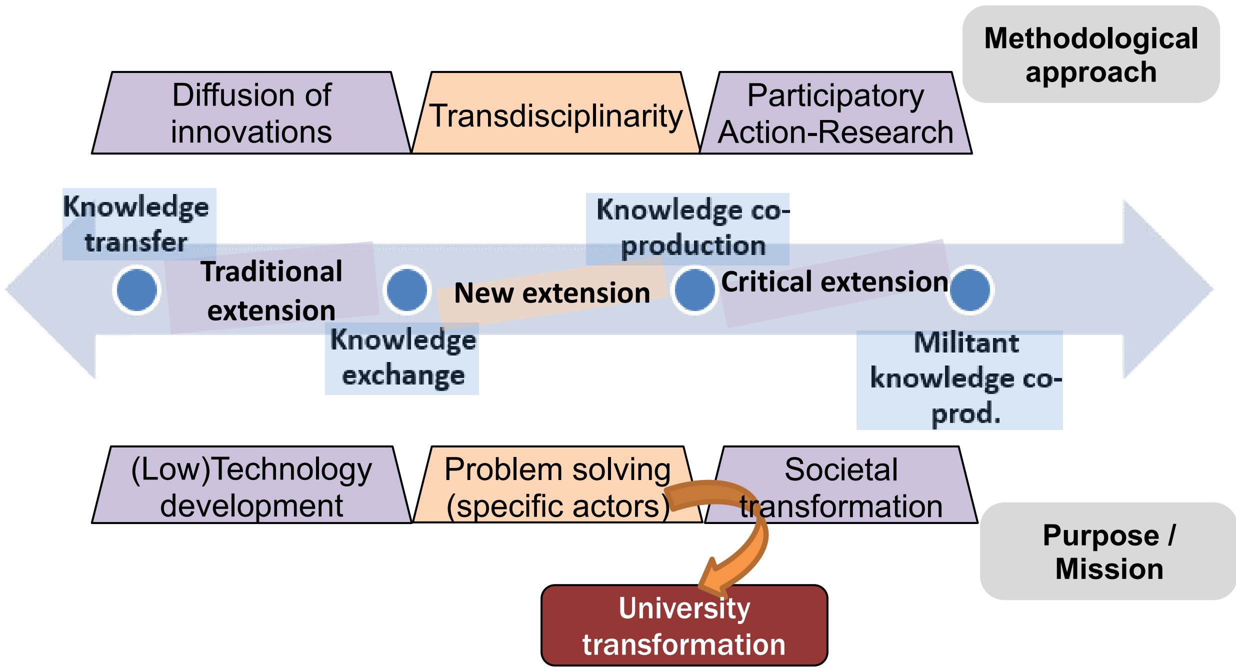

Figure 45: Different university extension models, their purposes and associated methodologies. In violet, the models proposed by Tomassino and Cano (2016). In orange, the new transdisciplinary extension we identify. Source: Villalba (2019)

In Figure 45, we summarize the characteristics of the two (ideal-type) models as identified by Tomassino and Cano (2016) regarding how knowledge is managed, the purpose or mission, and the main methodologies used. We also include a third (and middle-way) approach called the *new extension model*, related with the transdisciplinarity field. Indeed, we argue that in Argentina today, there is a third and mainstream extension approach, supported by a solid institutional structure (see below). This model shares a fundamental characteristic with the critical approach: the aim of transforming the way the university functions by bringing students closer to the solution of real-world problems.

Besides models, the concrete application of the LAE has been conditioned by political swings and the continual interruption of the democratic processes by regular military dictatorships and violent conflicts. In Argentina, six dictatorships took place in the 20th century: 1930-1932; 1943-1949; 1955-1958; 1962-1963; 1966-1973; 1976-1983. The last one was the worst regarding the number of crimes (30.000 missing, murders, 500 children misappropriations, rapes, etc.). It is also considered as one of the bloodiest dictatorships of the so called *Operación Condor*, the coordinated action plan financed and supported by the United States in Latin America (see for example Grandin, 2011). In the last decades, the democracy continuity and (in the first decade of the 21st century) the simultaneous progressist governments in different Latin American countries marked a period of renewed interest for and relevance of extension activities.

7.4 The institutional structure of the LAE in Argentina

The new extension model that we included in Figure 45 is, as we mentioned earlier, anchored in a well-developed multi-level institutional arrangement. This is represented in Figure 46.

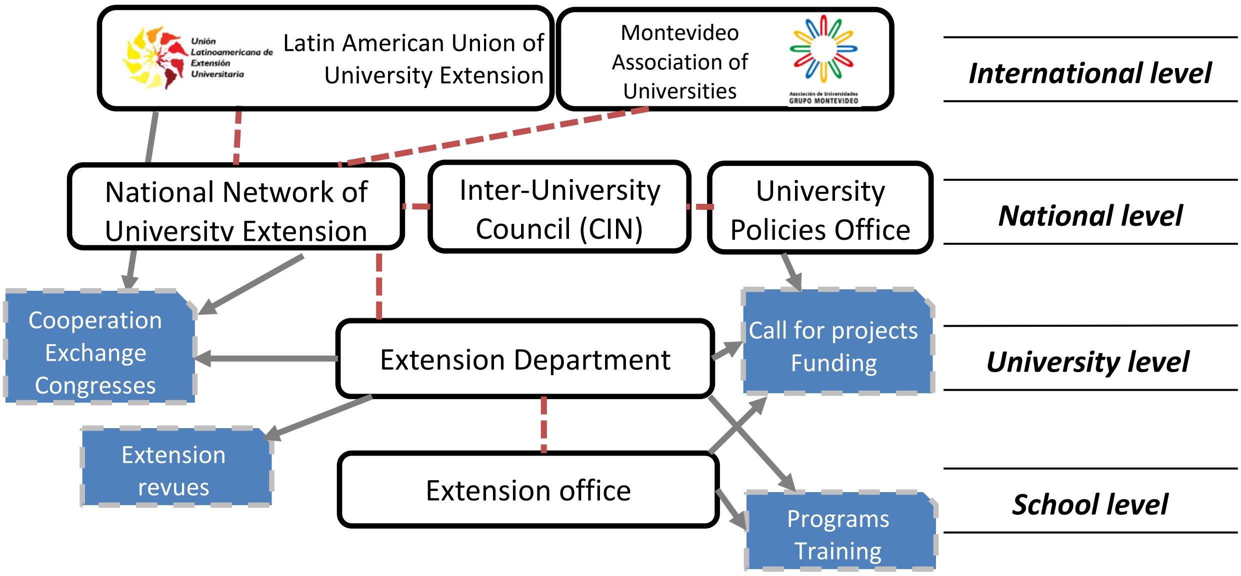

Figure 46: The institutional structure of the LAE. Source: based on Villalba (2019)

The LAE is institutionalized at the international, national, university, and school levels. At the international level, we can mention the Latin American Extension Union[53] and the Montevideo Association of Universities[54]. Both organizations promote the cooperation between universities and organize meetings and congresses. At the national level, there are National Networks of University Extension in Argentina, Ecuador, and Brazil. These organizations congregate the extension referents of local universities and are also a space of exchange and cooperation. In the case of Argentina, the National Network (Rexuni) depends on the Inter-University Council, which nucleates all national universities of Argentina. At the national level we also have the University Policy Office, which provides funding in the context of specific project

53 See www.uleu.org.
54 It is a network of public universities from Argentina, Bolivia, Brazil, Chile, Paraguay, and Uruguay which share vocations, public character, similarities in academic structures that place them in a position to develop cooperation activities with certain feasibility perspectives. It has a permanent commission on University Extension. See http://grupomontevideo.org/sitio/

calls[55]. Finally, we have extension departments and offices at the University and School level, with specific project calls (in general, with small funding) and training courses. In Argentina, several universities have their own Extension revue[56].

One of the particularities of the LAE is that it has been defined in the context of institutional documents. In Argentina, the following definition of University Extension, which is used as a reference for all the national universities, has been adopted by the Inter-University Council (CIN, 2012):

> *We understand extension as a space for cooperation between the university and other actors of the society it belongs to. This area must contribute to the improvement of people's quality of life and is linked to the social purpose of Higher Education: social democratization, social justice, and the right to a universal education. It materializes through concrete actions with social organizations, governmental organizations, and other institutions of the community, preferably through multi and interdisciplinary perspectives. Extension actions should be developed from an interactive and dialogic approach between scientific knowledge and the knowledge and needs of the participating community. The extension contributes to the generation and articulation of new knowledge and new social practices, integrates the teaching and research functions, should contribute to the definition of the research agenda, and be reflected in curricular practices*[57]

In our opinion, this definition fits very well the definition of transdisciplinarity presented in section 3.4 Transdisciplinarity: research, process, and challenges. That is

[55] In 2018, three call for projects related to the University Extension were financed: 1) University, Culture and Society; 2) University social commitment; 3) Technological linking.
[56] Iucci and Cardozo (2018) review 41 university extension revues in the LAC region.
[57] Our translation. The original quotation is: "Entendemos la extensión como espacio de cooperación entre la universidad y otros actores de la sociedad de la que es parte. Este ámbito debe contribuir al mejoramiento de la calidad de vida de las personas y está vinculado a la finalidad social de la Educación Superior: la democratización social, la justicia social y el derecho a la educación universal; se materializa a través de acciones concretas con organizaciones sociales, organizaciones gubernamentales y otras instituciones de la comunidad, desde perspectivas preferentemente multi e interdisciplinarias. Las acciones de extensión deberán desarrollarse desde un enfoque interactivo y dialógico entre los conocimientos científicos y los saberes, conocimientos y necesidades de la comunidad que participa. La extensión contribuye a la generación y articulación de nuevos conocimientos y nuevas prácticas sociales, integra las funciones de docencia e investigación, debe contribuir a la definición de la agenda de investigación y reflejarse en las prácticas curriculares".

why we included transdisciplinarity as the main methodology to put the new extension model presented in Figure 45 in practice.

This is also reinforced, in our view, by two main features of the University Extension: its aim of integrating research, teaching, and extension functions, and its main current implementation strategy: the extension projects.

Regarding the first, which in extension literature is referred to as the objective of achieving the "*integralidad*" (Arocena et al., 2017; Tomassino and Cano Menoni, 2016b), it is recognized as one of the biggest challenges of the full implementation of the extension purpose. In Argentina, an important progress in this direction was Resolution 692/12 of the Ministry of Education, which reads:

> *Considering,*
>
> *[...]*
>
> *That the academic community considers that extension does not refers to the sole act of transferring the results of the scientific production to society, but in "producing" in terms of the problems and demands that emerge from the interaction between university and society, which implies that its realization should be done in a dialectic process in which society and university enrich mutually with new knowledge and new problems to investigate by the university.*

Then, the Resolution recommends to all universities and higher education institutions to positively value extension experience of teachers when evaluating their academic work, encouraging the integrity of functions.

Regarding the second mentioned feature, as explained above and schematized in Figure 45, calls for projects are promoted at different institutional levels (the higher the level, the higher the funding available for projects).

As an example of what kind of projects these calls evoke, we present below the definition of what is considered an Extension Project in National University of the Centre of the Buenos Aires Province, in Tandil: "*a project aimed to solve problems defined jointly with social actors external to the university seeking concrete transformative actions*". For this call, it was imperative to work with more than one

University School and at least one civil organization, thus promoting inter- and transdisciplinarity.

In summary, we consider that LAE is an adequate platform to apply transdisciplinary research in Argentina. In our opinion, it is important to note that in the extension literature there are no references to transdisciplinarity research literature. Therefore, constructing bridges between both fields is possible (Villalba, 2019) and may constitute matter of future work.

8

Introduction to the thesis' articles

In this chapter, we first present the LAE -transdisciplinary- project in which the articles of this thesis were developed. Then, we introduce the 3 articles of the thesis.

8.1 A transdisciplinary extension project for addressing the IRS situation in Tandil

In 2015, after our[58] participation in an extension project with waste pickers at the school level (see Figure 46 in previous chapter), we were contacted by the local university[59] Extension Department Director, who proposed us to apply to a call of projects at the national level. This call corresponded to the University Policies Office (UPO), dependent on the Ministry of Education. It was framed in the program "Education on Cooperative movement and Social and Solidary Economy (SSE) in the University" of this Office.

The requirements of the project call were (Res. UPO 1615):

1) Direct participation of a Cooperative or SSE entity
2) A problem-solving approach, for problems defined by the Cooperative or SSE entities
3) Articulation with municipal/provincial/national organisms
4) Interdisciplinarity work approach, articulating research groups, university chairs, within and between universities
5) A concrete investment (human resources, economic) from the counterpart (cooperative or SSE entity)

[58] In this case I refer to the group of researchers of the Centre of Research and Environmental Studies (CINEA) who were working on waste management issues. The group was formed by: Roxana Banda Noriega (head of the group), Rubén Donalisio, Nicolás Cisneros Basualdo, Adriana Díaz, Beatriz Sosa, and the author.

[59] The National University of the Centre of the Buenos Aires Province (UNICEN)

We presented a project that was approved in December 2015 and started operationally in March 2016. Most of our work was framed in and financed by this transdisciplinary project.

8.1.1 The project's objectives

The general objective of the project was to "analyse the formal and informal management of urban solid waste (MSW) in Tandil city and the development opportunities of the Cooperative movement and the Social and Solidarity Economy in this area, through the generation of information to support a responsible decision-making regarding social, environmental, and economic perspectives". The second part of the general objective responded to our concern about the modernization project announced by the Municipality.

The specific objectives of the project were grouped according to two main purposes: 1) To analyse the MSW management system and its possible future scenarios, and; 2) To put in value and to strengthen the role of the recently formed Waste Pickers Cooperative. In this sense, we adopted a critical extension approach, which responded to our conception of the extension function in the university.

Moreover, the project was operationally organized according to three drivers: 1) working with UNICEN's chairs; 2) exchanging and joint-reflecting for problem-solving with all the participating institutions and with actors of the management of Tandil MSW; 3) co-creating knowledge with cooperative's and other institution's actors.

8.1.2 The project team

The project team involved actors representing the cooperative (waste pickers and non-waste pickers), the civil society organizations working on waste recovery, the Municipality (represented by its Environmental Office Director), the academia (with representatives of the Engineering, Humanities, and Hard Sciences Schools at UNICEN, and of the Architecture, Urbanism and Design School at Universidad Nacional de Mar del Plata), as well as a local Technical secondary school.

Figure 47 reproduces a poster presented at the Extension Projects Workshop at UNICEN (2017) which summarizes the activities carried out in the context of the project.

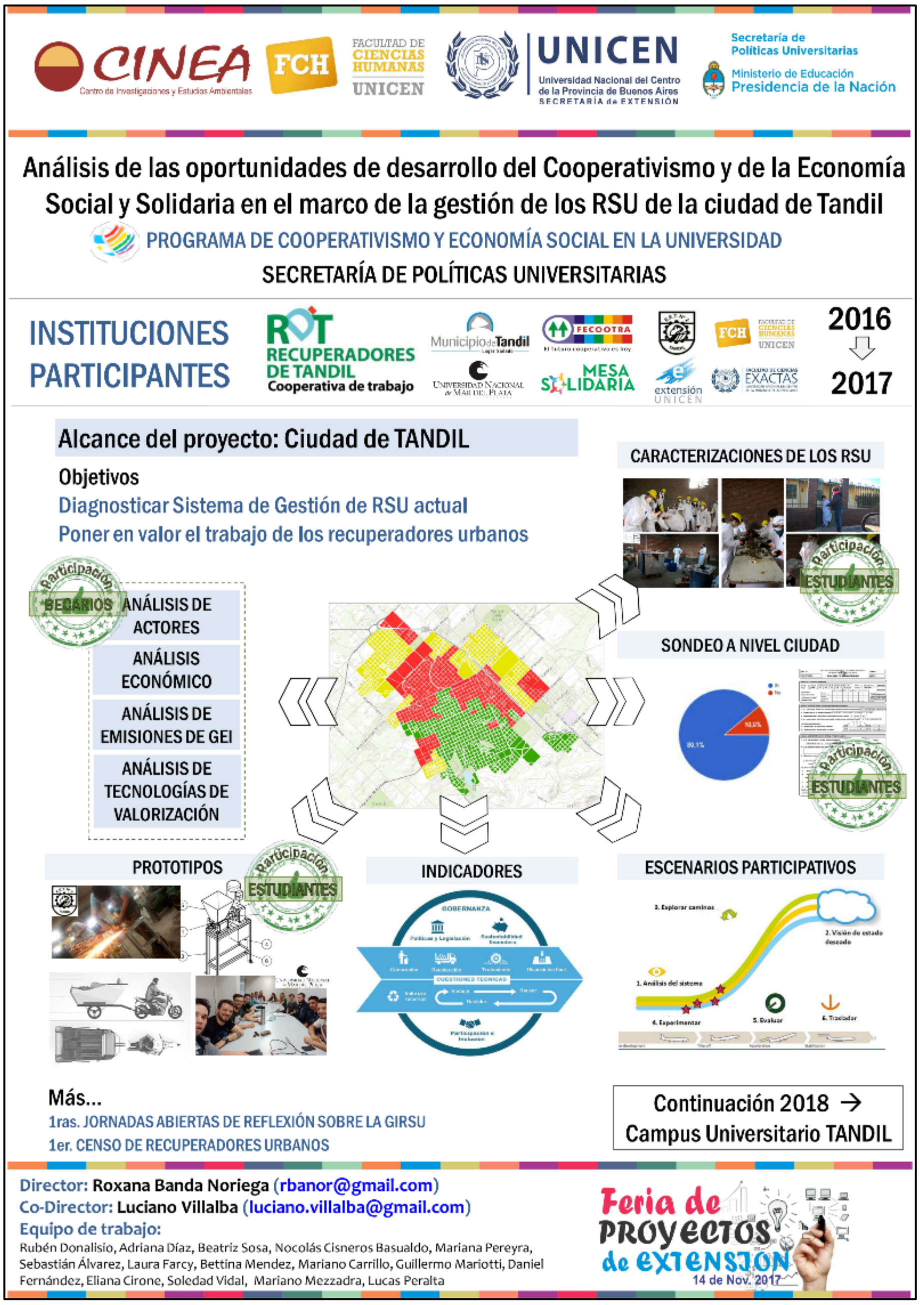

Figure 47: Poster presented at the Extension Project Workshop of UNICEN, in 2017

8.1.3 The author's role in the project

First, I was in charge of planning and writing the project proposal, since I had had a pro-active role during the previous extension project (see Section 8.1.2.2) and also because of my Ph.D. thesis, which was finally focused on this subject. In the formal aspect, I was one of the two Co-Directors of the project[60]; in the flied, I was its coordinator.

[60] This was possible because in this type of calls for projects (related to university extension) the associated formal requirements are less strict than in other calls.

8.1.4 Relation between my thesis and the transdisciplinary project

A significant part of my thesis's work is related to this project, either because of activities directly associated with it (like the waste characterization; see Ch. 9) or because of opportunities that opened later by reason of the results of this project (see section 8.5).

However, all the theoretical work that I presented in Ch. 2, 3 and 7, the analysis of the waste characterization raw data (see next section and Ch. 9), the use of Material Flow Analysis (see section and Ch. 10) or of the methodology InteRa used in Ch. 11, are exclusive results of my work[61].

Moreover, once this project ended in 2017, I was the only member of the research group that continued to work with the IRS. I directed a new extension project at the university level (2018-2019) called "Blue points for inclusive recycling and integrated education" in which I accompanied the formation of the IRS Cooperative "Environmental Promoters" program (Fernández and Villalba, 2019).

8.2 Introduction of the thesis articles

To describe the articles of the thesis, we will refer to the three types of knowledge used to characterize transdisciplinarity (Pohl and Hirsch Hadorn, 2007): target knowledge, system knowledge, and transformation knowledge. Indeed, the work done in the context of this thesis involved all three of them. Figure 48 illustrates the relation between the three types of knowledge and the phases of our work.

Target knowledge was mainly part of the theoretical research of this thesis. However, part of this knowledge was obtained as the result of transformational knowledge, from the boundary work done in interaction with other actors (Figure 48).

The system knowledge, which is mainly superposed with the system analysis phase, included the waste characterization of the city and the use Material Flow Analysis (MFA) to calculate indicators (Ch. 9 and 10). Importantly, in our overall work, MFA was used as a knowledge integration tool (Scholz, 2011a; Scholz and Steiner, 2015c)[62].

[61] By this I mean that I deal with frameworks and methodologies that were not part of the research group background and even today, I am the only one working with these tools.
[62] As for the way we used it, we could call it an agent-oriented Material Flow Analysis (Binder et al., 2004; Lang et al., 2006).

The project included other diagnose tools, such as a household survey that I designed, but they are out of the scope of this thesis.

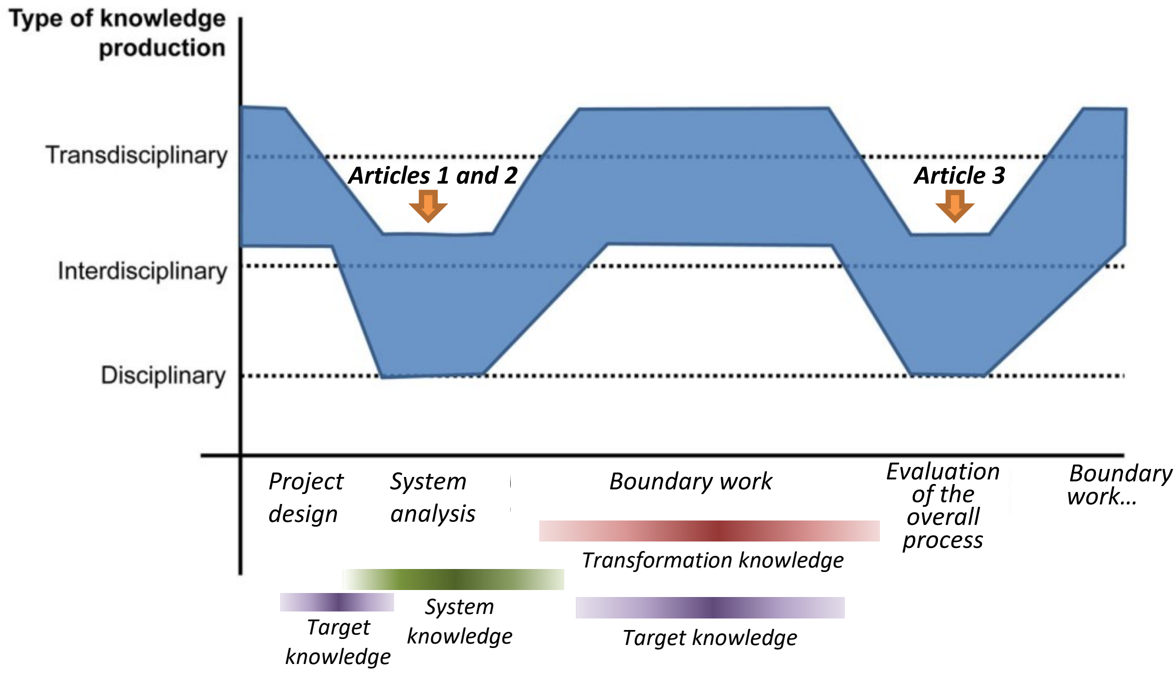

Figure 48: The interaction of the different types of knowledge production, the different phases of the transdisciplinary project, and the three types of knowledge. Source: modified from Binder (2014)

As we will see in the next sections, transformation knowledge, that is, knowledge "related to 'possible means of acting that aim to transform existing practices and introduce desired ones'" was concretely addressed in a phase of boundary work. It was a phase of "learning-by-doing and doing-by-learning" (Loorbach, 2007[63]), in which we encountered significant limitations to include relevant actors in the problem solving activities we organized. The disciplinary work was, in this sense, a refuge where we found fewer barriers for the generation of new knowledge.

The transdisciplinary process was also affected by changes not related with our work. The way we evaluated the evolution of the IRS integration in the overall process was to use a specific tool called InteRa (Ch. 11).

8.2.1 The target knowledge

Part of this knowledge was the conceptual base upon which we constructed the present thesis. In Chapter 2, we addressed, in fact, what we can considere a model of waste management for developing countries. That is because, as Scholz and Steiner (Scholz

[63] For Loorbach (2007) this process is at the heart of transition management.

and Steiner, 2015a, p. 532) states: “[i]n a sustainable transition, what the target state looks like is not exactly known, and neither is how sustainable or unsustainable the present (initial) state is—or sometimes even the type of barrier”. We first analysed the relation of WM with a more general approach: that of the circular economy (Chapters 1 and 2).

We concluded that the waste issue must be tackled at different levels (local, regional, and national/international). Then, we focused on the local level, reviewing a framework of integrated sustainable waste management specially adapted to developing countries and enriching it with developments made at the regional level. Moreover, we deepened in the role of the IRS in ISWM, particularly in the LAC region. We presented the concept of *inclusive recycling*, which is today a regional reference in how to integrate the IRS in the formal waste management.

8.2.2 The system knowledge: Articles 1 and 2

The system knowledge, that is the understanding of how the system is working, was a main part of the work made through the articles submitted to peer review.

In the first article (Villalba et al., 2020), reproduced in Ch. 9, we present the results of the first waste characterization performed in Tandil through a standardized method. It is the only article in which I am not the only author.

As developed in the Introduction of the article, waste characterization data has multiple uses and is considered basic information of waste management systems.

Figure 49: Part of the work team during the first waste characterization. Photo credit: Roxana Banda Noriega

This work was performed by a team of researchers and students. My role was to plan the waste characterization samplings and the organization of the daily work during the operational phases. Also, I was responsible of gathering and processing data, and analysing results. Then, I wrote alone the research paper. In this process, which took roughly a year, I learned about some technical limitations of the typical composition result analysis (in %) and I overcame them by focusing our analysis in the kg/pers/day generated by waste category. This was possible because we performed a door-to-door characterization. Also, I identified several specificities in our results related to the high loss of mass during the picking analysis. I associated this with the consumption of yerba mate, a traditional habit of our region.

In Article 2 (Villalba, 2020a), transcribed in Ch. 10, I applied the Material Flow Analysis methodology in an iterative manner and with different purposes. First, I used it to describe how the system works. Then, I used it to calculate a set of indicators intended to evaluate the current recovery strategies in place, formal and informal, which was carried out by using waste characterization data and other primary and secondary information sources. Moreover, I quantitatively estimated the amount of waste that was illegally disposed in open dumps.

With this information, we analysed how the system functioned regarding the ISWM framework (target knowledge) as well as the legal framework. Therefore, this article also reflects part of the target knowledge we developed in Ch. 2.

8.2.3 The transformation knowledge: dealing with emergency *and* surprise

This part of our work was mostly out of our control because it was carried out in interaction with practitioners and policymakers and because we failed in involving the municipal government in any of the planned activities we proposed. In other words, we failed to implement the methodologies reserved to the co-construction of a long-term vision for the waste management of Tandil.

Also, it is important to note that unexpected events both at the organization (cooperative) level and at the national level (landscape changes) took place during our work which severely affected the situation of the IRS both positively and negatively (see Ch. 11).

In the next sections we present the main activities we carried out in this phase.

8.2.3.1 The workshop Separando juntos *(Separating together)*

Driven by the idea of organizing a network of people sharing the common objective of improving the waste recovery system, on 29 October 2015, I organized a first participative workshop to get the actors working in the waste recovery of recycling materials together.

The workshop was intended to gather representatives of different organizations. We expected between 7 and 12 people from different institutions as well as the Municipality to participate.

Figure 50: A moment of exchange during the workshop. Photo credit: the author

Ten people attended. The result of the workshop was shaded because of the unexpected absence of the Municipality representative. However, a positive environment prevailed since it was the first time that most actors working in materials recovery had been gathered. For the participants, I became a referent in the matter.

Different proposals arouse from the workshop, mainly focused on the importance of environmental education, the commitment of the actors currently working with recycling, and the need for an active role by the Municipality.

8.2.3.2 The creation of the Mesa GIRSU: emergence of a boundary organization for ISWM

Worried about the plans of the mixed-waste treatment plant and conscious of alternatives and the work of waste pickers, an elected councillor of the city decided to organize all the political parties and the civil organizations working in waste management in a Permanent Table on integrated Solid Waste Management (*Mesa GIRSU*) in July 2016. After a few meetings, they decided to invite the local university to participate. Since we were already working with the civil organizations, I asked them to become the representative of the university, which was accepted. Since then, I am the coordinator of the *Mesa GIRSU*: I am in charge of making the minutes of the meetings and I take a pro-active role to maintain the meeting dynamics[64].

The work of the *Mesa* was marked from the beginning by a refusal of the municipal government to keep a representative. The Municipality sent two persons to the first meetings, but they never attended subsequent meetings again. Since then, we are seen by the local government as an “opposition” organization. Moreover, not all the civil organizations accepted to participate, arguing that they were overwhelmed with their daily work[65].

In more than three years of work, we made many different actions. I will summarize them in what follows.

8.2.3.2.1 Constructing a shared vision of the Integrated Solid Waste Management

One of the first agreements between participants was the need for a shared vision of what a desired waste management represented for us. As the representative of the University, I was asked to prepare a document summarizing the state-of-the-art in the matter. The summary I presented is developed in Ch. 2 and 3. After internal debates, we agreed to adopt this framework as the ISWM vision of the *Mesa*. Then, I constructed a diagram to easily transmit the essence of the approach (Figure 51).

[64] The Mesa GIRSU meets once or twice a month in non-electoral years. Meetings are open to public participation. In electoral years, since we have several political candidates participating in the table, and political campaigns are intense in Argentina, we space the meetings and / or work online.
[65] After three years of work, only the cooperative of waste pickers participated without interruptions.

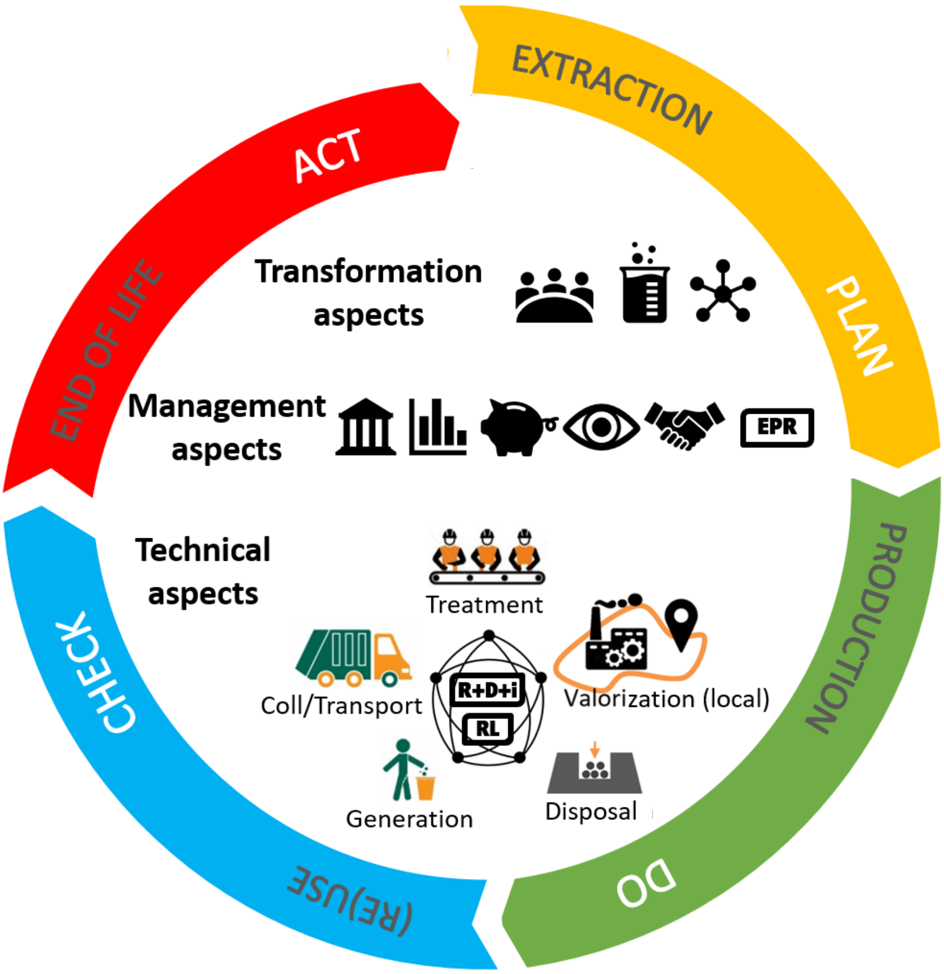

Figure 51: English version of the diagram used to explain the framework adopted in the Mesa GIRSU. A further explanation of the framework is available at the web site (www.mesagirsu.org)

8.2.3.2.2 Creating a hybrid forum

The *Mesa* started to promote its work through different channels: mass media (journals, TV, social media) and later the creation of a web site (www.mesagirsu.org). The web site, which I designed and created using the Wix platform, offers information related to the work of the *Mesa*, a timeline showing the evolution of waste management in Tandil[66], as well as an ISWM monitor where we present quantitative information related to tons of waste disposed in the landfill and waste recovered, among others. Starting in August 2019, we incorporated a Blog aimed at promoting waste-related information and news.

8.2.3.2.3 The Mesa GIRSU boundary objects: Ordinance proposals

The *Mesa* has also been a space where research results were used as support information for concrete ordinance proposals. Using a legislative mechanism called

[66] This idea was inspired by the work made on controversies analysis.

Banca XXI that allows persons or institutions to present ordinance projects to be evaluated by the Legislature, we proposed two projects.

The first ordinance project is a legal framework for large waste generators and was presented in May 2018. This project highlighted the results we obtained in Ch. 9, which showed that households generate less than 50% of waste arriving to the landfill.

The second ordinance project was aimed at regulating the circuit of private waste skips. It highlighted the findings of our second article, were we used MFA to estimate, among other indicators, the amount of waste illegally disposed in open dumps[67].

In 2020 we presented, through one of the political parties represented in the Deliberative Council, an ordinance project to assign 1,5% of the "general services" tax (in which solid waste management is comprised), to finance: 1) awareness campaigns for waste reduction and other projects related to the 3R,and; 2) the associations which recover materials, on the basis of the quantity of tons they collect.

All the projects are still waiting for treatment.

8.2.3.2.4 Other activities

We also organized specific activities such as open talks or a participative SWOT analysis performed in 2017 (Figure 52).

Figure 52: Participants of the Mesa GIRSU in a participative SWOT analysis that I organized in 2017. We can distinguish the use of MFA as an integration tool and the ISWM framework scheme we used. Credit photo: the author

[67] Both ordinance projects are available at www.mesagirsu.org.

8.2.3.3 The cooperative dissolution and rebirth

One of the unexpected situations we had to deal with was the dissolution of the cooperative of waste pickers in the late 2016. Even if the extension transdisciplinary project continued because it involved other actors, this situation threatened its overall aim. Fortunately, there was a turn of events in 2017 for which a fresh start for the waste pickers cooperative took place. This is explained in Ch. 11.

8.2.3.4 The planned but not performed workshop "Towards an Integrated Sustainable Waste Management"

Finally, we knew that including the members of the local government was imperative for the co-creation of a vision of the future of waste management. We therefore planned a series of workshops not to be held in the *Mesa GIRSU*, but in the context of the 50 years of the CINEA, our associated research lab.

However, we never succeeded in engaging the municipal personnel.

8.2.3.5 The social emergency Law: a change in landscape that changed everything

Finally, in the third article (Villalba, 2020b; Chapter 11) we analyse a major unexpected change taking place at the national level which allowed the organization of the waste pickers to advance very quickly: the passing of the Social Emergency Law. This Law reached the waste pickers because they are considered part of the "popular economy", a boundary concept that emerged some decades ago in the context of a socioeconomic crisis.

In the next Chapters, we present the articles of the thesis[68].

[68] To keep their original format, each article includes its own list of References, even if they are also available in the general References chapter of the thesis.

9

Article 1: Household solid waste characterization in Tandil (Argentina): socioeconomic, institutional, temporal and cultural aspects influencing waste quantity and composition

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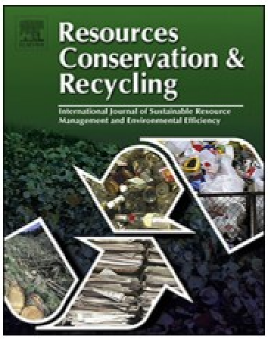


Highlights

- Door-to-door allows the use of kg/person/day by waste category to compare strata
- No statistically significant differences were found between High, Medium and Low SES
- Municipal solid waste generation rate in households of Tandil is 0.401 kg/person/day
- *Yerba mate* residue may be contributing with more than 10% of the local organic waste

Abstract

Household waste generation and composition information is a fundamental input for waste management policy design. In developing countries (DC), however, budget constraints make some characterization methodologies inadequate. Following a methodology specially designed for DC, we performed the first door-to-door municipal solid waste (MSW) characterization in Tandil, a city of 130,000 inhabitants. We stratified households into three socioeconomic status (High, Medium and Low SES) using Geographical Information Systems and census data and performed three one-week sampling campaigns over a year. Results indicate that the generation rate of waste produced in households is 0,401 kg/person/day, less than 50% of the waste arriving at the local landfill. We analysed the normality of data associated with generation rates per category of waste (in kg/person/year) through Shapiro-Wilks tests and Q-Q plots, finding that most of them were normally distributed. Using these categories, we compared strata using ANOVA and Tukey tests, finding that strata waste compositions were similar. We registered a high mass loss during picking analysis - more than 3% in autumn and more than 5% in late spring-, which may be related to organic matter humidity evaporation. We compared daily average mass losses with daily average working-hour temperatures, finding a coefficient of determination r^2 of 0,7. Finally, we analyse the consumption of yerba mate -a typical South American habit- as an important source of organic waste and waste moisture content in Argentina.

Keywords:

Municipal Solid Waste

Household waste composition

Mass loss

Generation rate

Door-to-door characterization

Developing countries

1. Introduction

Solid waste management is one of the most challenging activities for municipalities in developing countries (Scheinberg et al., 2010b). In Latin America and the Caribbean (LAC) region, where 80% of people live in cities, Municipal Solid Waste (MSW) generation is expected to grow 60% by 2050 (Kaza et al., 2018). At the same time, most LAC countries lack vital information to improve waste management policies (ONU Medio Ambiente, 2018).

Information about waste composition and characterization is a fundamental input for waste management policy design (Christensen, 2011a). It is highly accepted that those parameters vary widely, depending on the urbanisation degree, the GDP per capita, the regional food choices, and many other local factors (Edjabou et al., 2015; Tchobanoglous et al., 1982). However, cities in developing countries (DC) frequently miss this information, and waste-related decisions are often taken either blindly, or on the basis of national average rates that may be far from the local reality -if available at all- (Miezah et al., 2015; ONU Medio Ambiente, 2018).

In Argentina, waste characterization is not promoted by the national government and detailed and robust analyses are available only for the City of Buenos Aires, a high-density metropolis of 2.9 million inhabitants (Giorgi et al., 2015). General statistics - segregated by city sizes- are available (ARS, 2012), but their usefulness can be only partial and contested because they are calculated as averages of cities belonging to very different geographical areas.

Although there is a wide variety of methodologies for solid waste characterization, obtaining local information is generally not straightforward, and special consideration must be taken in developing countries. Flintoff (1980) reviews different methods for MSW sampling in developing countries and analyses how waste information can be lost at every stage of the waste management process. From generation at households to deposition at landfilling, the feeding of animals with food waste and the work of wastepickers are the main sources of waste information loss (ibidem).

Dahlén and Lagerkvist (2008) reviewed and analysed eighteen methods for household waste composition studies based on physical sampling (see below) and two methods based on material flows (e.g. Franklin and Associates, 1999; see also US EPA, 2006).

The use of methods based on material flows (indirect measurements) need accurate market information (Baccini and Brunner, 2012; Brunner and Ernst, 1986), which is hard to obtain at the local level and more generally in DC. In Argentina, for example, the shadow economy represents more than 25% of the GDP (Schneider et al., 2010), making the use of this kind of methods inappropriate.

Within the direct physical methods, some focus on the overall Municipal Solid Waste (MSW), that is, waste generated in households and similar waste generated in other sources like offices, public facilities, and commerce (e.g ASTM, 2016 [2003]; Reinhart and McCauley-Bell, 1996), while others focus only on a single source, such as households. As an example of a direct physical method, the ASTM (2016) test is of interest because it is the source of available data for Argentina (CEAMSE, 2016; Giorgi et al., 2015) and because a corresponding standard document is available in the Argentinean Institute of Normalization and Certification (IRAM, 2003). According to this method, the primary sampling units are MSW collection vehicles and the survey should last, at least, a week.

Sampling vehicle loads present, however, some limitations that make them particularly inappropriate for little or medium size cities of developing countries. For example, important equipment such as the front-end loader, should be available or rented. Also, recyclable waste can be collected by wastepickers before trucks collect the waste (Flintoff, 1980), compaction can hinder waste analysis (European Commission, 2004), stratification can be affected (Sahimaa et al., 2015), and deciding on the number of samples can require a large amount of historical data, which may be unavailable. Importantly, some waste fractions may be not normally distributed, suggesting more advanced statistical computation (Edjabou et al., 2017; Lagerkvist et al., 2011). Finally, the information obtained is limited because it is hard to associate the sampled waste with the source and number of people who generated it (Dangi et al., 2008). This information can be precious if recycling strategies target only a sector of the waste management system, such as only households or only commercial activities.

Waste characterization methodologies designed for developing countries are generally focused on a single source, households (Cantanhede et al., 2005; Dangi et al., 2011, 2008; Mbande, 2003; Miezah et al., 2015; Sakurai, 1983). They are intended to be of simple application and requiring only basic instruments and materials. Also, they allow to avoid the mentioned shortcomings of methods sampling vehicle loads.

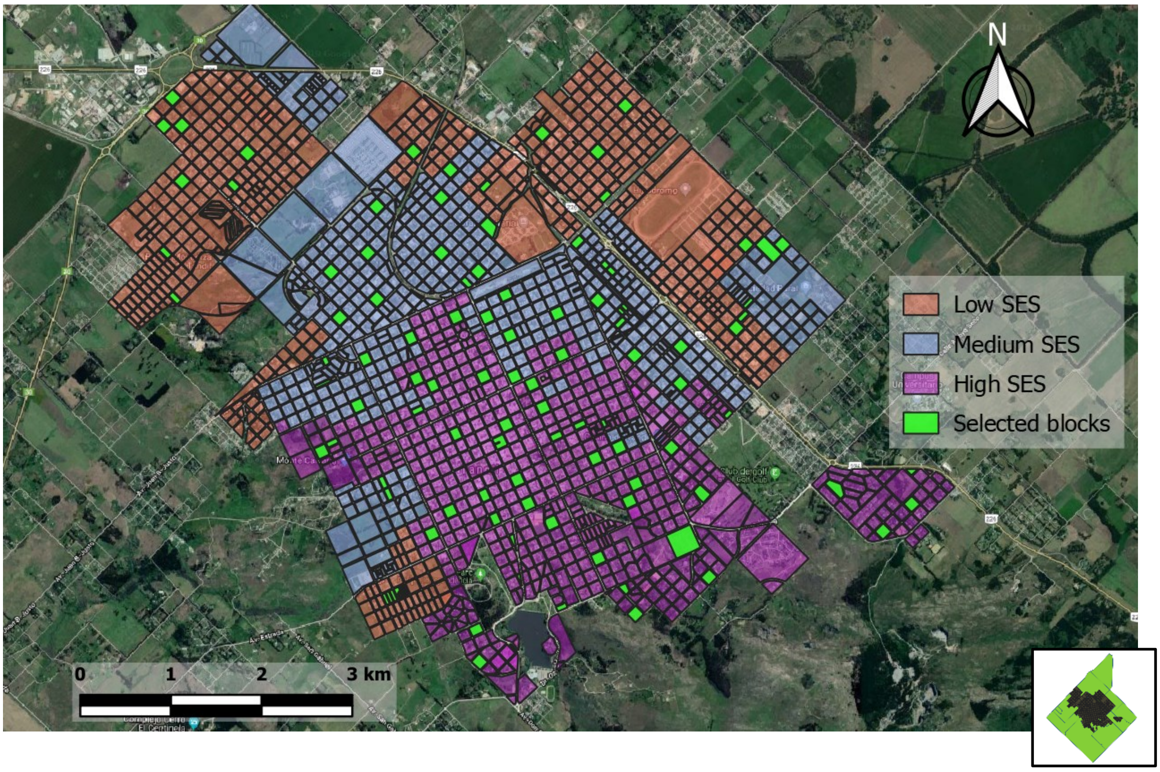
In this work, we present the results of a study conducted with the overall aim of evaluating the characteristics of waste composition and generation rate of households from Tandil city (Buenos Aires), following the Kunitoshi Sakurai's methodology for MSW analysis (Sakurai, 1983). Stemming from this overall aim, our specific objectives were: 1) to perform a stratified house-to-house characterization of waste under budget constraints; 2) to evaluate the quality of obtained results and compare them with other studies; 3) to analyse the relation between these results and local cultural habits.

2. Material and methods

2.1 Study area

Tandil city is located at the southeast of Buenos Aires province (37° 19.5'S; 59° 08.3'W). It is the head city of Tandil county, which includes four other towns. In 2010, the city had 116,500 inhabitants living in 40,756 households (Edwin and INDEC, 2012). With a total urban area of approximately 50 km2, the city follows a sprawl model of growth (Fernández and Ramos, 2013), as other Latin American cities (Inostroza et al., 2013; Rojas et al., 2013). Figure 1 shows the city map, where we can see the typical square households blocks as most cities in Argentina.

Figure 1: Map of Tandil with the three defined Socioeconomic Status (SES) strata and the random selected blocks. In the right-down corner, in green, the census blocks removed from the study; in black, those we kept.



Tandil has two different waste management systems: one for mixed waste and the other for source-separated waste. For mixed waste, the city counts with a public kerbside collection service, covering the whole city with different collection frequency. Households, institutions, stores, etc., dispose their daily waste in plastic bags that are initially disposed at sidewalks, since waste bins are not used. Municipal compactor trucks collect the bags at the sidewalks and transport them to a sanitary landfill operated by a private company.

For source-separated recyclable materials, a bring system with three central collection points operate since 2015. These so called "Clean Points" receive, from households: paper and cardboard, glass, plastics (PET and PEAD), tetra brik containers, metals and WEEE. These materials are processed and sold by civil societies to finance their activities.

2.2 Main features of Sakurai's methodology

The formula to determine the number of samples, i.e. households needed, is based on the household waste generation rate (HWGR). For a 95% of confidence level, the formula is:

$$n = s^2/[(ex/1.96)^2 + s^2/N] \qquad [1]$$

where s is standard deviation of HWGR; e is the allowed error for the estimation (in percentage) of the HWGR and x is its mean value; N is the total number of households. If previous data is unavailable, estimation of HWGR mean and variance value is needed. Sakurai recommends doing a stratified random sampling based on socioeconomic information.

The study is developed along 8 consecutive days, but the first day is discarded. A proceeding of coning and quartering is suggested to homogenize samples before the calculation of volumetric weight. Sub-sampling or sieving of samples are not recommended. Furthermore, analysis of waste composition is not done for each bag or household but for each stratum.

2.3 Planning of the sampling

We defined the number of categories for waste classification considering which materials are recycled in Tandil and how they are processed. In this way we narrowed the scope of the study and improved the statistical significance of results (Dahlén and Lagerkvist, 2008). Glass, for example, is not separated by colour; a unique category of glass was therefore defined. As recovered plastics are PET and PEAD collected separately, we defined plastic fractions as PET, PEAD and Other plastics. All categories are listed in Table 1.

Table 1: Selected fractions for the characterization of the household waste

Fractions	Description
Organic waste	Mainly food waste and biodegradable waste not fitting in other categories (i.e., used table napkins)
Gardening waste	Biodegradable waste from domestic gardens

Paper	Office paper, notebooks, glossy magazines, etc.
Cardboard	Mostly packaging board, corrugated or not
Tetra Brik	Packaging waste made of Tetra Brik
Plastics	
PET	Polyethylene terephthalate; mainly bottles of domestic use
PEAD	Density polyethylene; mainly bottles of domestic use
Other plastics	Films and other plastic packaging, plastic objects, etc.
Glass	Mainly wine bottles and jam jars; other glass objects
Textiles	Clothes and sewing waste
Metals	
Aluminium	Cans, aluminium wrapping foil, etc.
Ferrous metals	Cans, food containers and other objects
Special waste (SW)	
WEEE	Phones, lighting bulbs, cables, battery chargers, etc.
Batteries	Single batteries/accumulators, rechargeable and not
Others SW (OSW)	Other household hazardous waste
Sanitary household waste (SHHW)*	Diapers, hygienic paper, pharmaceutical waste, dead animals, animal excrement, cat litter, etc.
Refuse miscellaneous waste	All waste not fitting in other categories

*For second and third sampling campaigns we included some sub-categories of SHHW, but their analysis is out of the scope of this paper.

2.3.1 Determination of the number of samples

For the application of the Equation 1, two basic parameters need to be assumed: 1) the mean x of the HWGR (in kg/person/day), to set the desired accuracy of results based on the percentage of error e, and; 2) the standard deviation s of the HWGR.

To estimate the HWGR mean, we first analysed the amount of waste monthly collected by trucks coming from households and commerce in the period 2010-2015 (see Table SI.1 of Supplementary Information). For 2016, a municipal solid waste landfilled rate (MSWLR) between 0.75 and 1 kg/person/day was estimated.

On the basis of previous data (see for example (Bernache-Pérez et al., 2001; Buenrostro et al., 2001; Byamba and Ishikawa, 2017; Miezah et al., 2015), we estimated that households contributed with 50-80% of waste arriving to the landfill, i.e. a HWGR within the range [0.375–0.8] kg/person/day. We carried out a simple sensitivity analysis to evaluate how the number of samples required varied according to different values of the HWGR mean, the percentage of error and the standard deviation, for a confidence level of 95% (see Table SI.2 of Supplementary Information). Considering the results of this analysis and considering resource and time limitations, we finally aimed to sample an average of 80 households.

2.3.2 Determination of socioeconomic strata using GIS

We used the national census data *(Edwin and INDEC, 2012)* mapped with ArcGIS to stratify households according to their socioeconomic status (SES). Census data is aggregated at the lowest level in census blocks, grouping 300 dwellings in average (INDEC, 2015a). As there is no income data in the national census, we selected 14 variables related to educational, social, and housing conditions (see Table 2).

Table 2: Information of the national census used to build the stratification.

N°	Census data variable
1	Illegal occupation
2	Overcrowding – Less than 0.5 persons per room
3	Overcrowding – More than 3 persons per room
4	Index of the quality of materials IV (CALMAT IV)
5	Index of the quality of materials I (CALMAT I)

6	House type – Hut
7	House type – Rancho
8	Houses with Unsatisfied Basic Needs
9	% Unemployed
10	% Employed
11	Academic achieved degree – Postgraduate
12	Academic achieved degree – University
13	Academic achieved degree – Tertiary
14	Academic achieved degree – Never assisted to school

Using the ArcGIS tool Grouping Analysis, we grouped similar census blocks according to these variables. We merged the map of census blocks with the map of the city square blocks and checked for overlapping. The resulting map is shown in Figure 1. In the Supplementary Information we provide further explanations of this step.

We removed the low-density census blocks (in green at the right-down corner of Figure 1) because it would have been operationally impossible to include households from them in the study. This meant a two-third reduction in the work surface, resigning only 3.6% of households. The structure of each stratum and the corresponding targeted number of samples is detailed in Table 3.

Table 3: Strata characteristics and corresponding number of samples targeted

Socioeconomic Status (SES)	% of HH 2010	% of people	Number of samples
High	43.20	38.92	31
Medium	37.43	37.84	30
Low	19.37	23.24	19

2.3.3 Systematic random selection of the city blocks

As a complete list of dwellings was unavailable, we used the list of the city square blocks as the sampling primary unit. We defined a selection step (p) as the ratio between the total number of square blocks in the stratum (N_h) and the number of samples to be taken from it (n_h). To make sure we had enough HH, we added +10 % to the calculated samples (e.g., instead of 31 samples for the High SES, we selected 34). We then generated one randomized number with a spreadsheet (n_a) for each stratum, and following the equation [2] we obtained the selected square blocks from the list ($S_{h,i}$).

$S_{h,i} = 1 + \text{ENT}(n_a \text{*p} + n_{h,i} \text{*p})$ [2]

where $n_{h,i}$ is the number of the sample (going from 0 to $n_h - 1$).

Selected blocks are shown in green in Figure 1.

2.4 Household recruitment

The recruitment campaign was carried out some days before the beginning of each study. For each randomly selected square block, we started from a predetermined corner and invited the dwellers of the second house of the block to participate in the study. In case they refused to participate, it was an abandoned house or a commerce, or nobody answered, we continued with the next HH. When a HH dweller accepted to participate, we followed the training protocol and gave them 8 plastic bags where the stratum code of the HH was indicated. Finally, we asked for contact information and asked about number of dwellers and age range (<6; 6-18; 19-60; >60). This information was used to check the representativeness of the population covered by the sample (see section 3).

2.5 Sample collection and processing

Each characterization campaign was carried out from Sunday to Sunday. We established four collection routes including approximately 20 HH each. This allowed us to use private cars for collection, thus minimizing costs. Waste collected the first day was discarded.

Once all collection routes were finished, we regrouped waste by stratum and weighed it on a daily basis. Then, for each stratum, we opened the plastic bags and performed the procedure of coning and quartering with the purpose of measuring the volumetric weight. All waste was processed in what followed, in order to avoid errors from waste splitting *(Dahlén and Lagerkvist, 2008; Edjabou et al., 2015; European Commission, 2004)*.

The next step was picking analysis, in which the stratum waste was classified in the defined material fractions. For special cases during sorting analysis (e.g. packaging items with contents or items consisting mainly of one category but with small parts of other), we mainly followed the recommendations of the SWA-Tool *(European Commission, 2004)*.

After classification of all the waste of one stratum, each fraction was weighed. Mass losses were calculated as the difference between weighed waste before and after sorting process.

2.5.1 Calculation of HWGR and waste composition

For the calculation of HWGR, we considered the quantity of waste generated by each stratum daily and the associated number of people who generated it. As recommended by the SWA-Tool, for the calculation of overall results of each campaign, measures of the single strata were weighed "according to its portion in the parent population" *(European Commission, 2004, p. 26)*. In this way, average results were calculated as "the weighed mean of the single stratum results." Standard deviation measures correspond to how composition and HWGR per stratum varied daily.

Waste composition data is presented as percentages of wet mass as suggested by Edjabou et al. (2015) and the SWA-Tool (European Commission, 2004) and also on mass per capita and day for fractions -such as organic waste in kg/person/day- for the strata comparison. In this way we avoided the constraints related to closed datasets analysis *(see Edjabou et al., 2017)*.

2.6 Second and third characterizations

The first study took place from June 5th to June 12th, 2016, the second study from December 11th to December 18th, 2016, and the third campaign from April 23rd to April 30th, 2017. Though the three waste characterization campaigns followed the main steps described previously, ~30% of households were renewed in each campaign.

3. Results and discusión

3.1 Sample evaluation

After each recruitment campaign, we compared the age-structure of the population sampled with the age-structure of the city population stated by the 2010 national census (Edwin and INDEC, 2012). The 19-60 age range percentage was the most stable during the three campaigns and also the closest to the census corresponding percentage: 53.87, 53.85 and 53.68% in each sampling campaign against 54.7% in the 2010 census. The 6-18 age segment was the second most stable percentage, with 18.45, 19.23 and 17.28% of sampled people versus 19.93% in the 2010 census. Less than 6 and more than 60 age range percentages were less stable but similar to census 2010 data.

3.2 Waste composition analysis

The resulted general composition and HWGR rate for each sampling campaign are shown in Table 4. Organic waste was the main fraction in each campaign, accounting for more than half of the waste. The second predominant fraction in the three cases was SHHW. This may be due to the broad definition we made for this category (see Table 1). Plastics and glass were relevant fractions, too. While participation of some materials remained stable during the three campaigns, such as organic waste, other plastics, metals or SHHW, other materials showed slight fluctuations. Glass and PET, for example, decreased and increased respectively at the end of the spring. This could be due to a smaller consumption of wine, which is the main source of glass waste, and to a higher consumption of soda beverages.

3.3 HWGR: comparison with other studies

HWGR calculated for each sampling campaign and stratum can be seen in the last row of Table 4. While general composition of waste remains approximately stable during the three campaigns, HWGR shows a steady growth. This may be explained by the general lower consumption rate of 2016, when Argentina GDP contracted 1.82%, and by its reactivation in 2017. Consumption levels had fallen abruptly in June 2016 (Ambito Financiero, 2016), month of the first sampling campaign, reaching rates similar to those of the 2001 crisis.

Table 4. Waste composition by campaign and stratum, in percentage of wet weight. In the last rows, for each campaign and stratum: average HWGR in kg/person/day; average number of HH and of people that participated

	End of autumn 2016				End of spring 2016				Beginning of autumn 2017				
	High SES	Medium SES	Low SES	Average	High SES	Medium SES	Low SES	Average	High SES	Medium SES	Low SES	Average	**General average**
Organic waste	57.20	55.25	51.92	55.24	55.21	52.70	52.91	53.72	50.30	49.15	60.78	52.3	53.75
Gardening waste[a]	0.22	0.60	0.91	0.52	2.24	6.88	1.06	3.72	1.63	7.49	1.30	3.77	2.67
Paper	6.26	4.41	4.76	5.21	6.03	3.65	3.84	4.62	4.25	3.69	2.53	3.64	4.49
Board	3.52	3.26	2.41	3.16	3.41	2.32	2.82	2.86	3.13	3.03	2.39	2.92	2.98
PET	1.83	1.96	1.30	1.76	2.31	2.10	2.29	2.23	2.01	1.77	1.64	1.83	1.94
HDPE	0.49	0.59	0.55	0.54	0.55	0.68	1.33	0.78	0.63	0.46	0.61	0.56	0.63
Other plastics	8.79	6.57	6.93	7.52	7.87	6.77	6.94	7.24	7.05	6.81	7.14	6.98	7.24
Glass	7.50	7.58	7.07	7.43	4.91	4.70	5.64	5	10.17	6.94	3.64	7.43	6.62
Textiles	0.89	0.77	2.07	1.12	1.36	2.22	2.43	1.93	1.10	2.00	1.09	1.44	1.5
Aluminium[b]	0.29	0.19	0.25	0.24	0.40	0.22	0.23	0.29	0.38	0.18	0.13	0.25	0.26
Ferrous metals	1.23	0.59	0.83	0.89	0.73	0.95	1.14	0.91	0.94	0.79	0.93	0.88	0.9
Tetra brik	0.79	1.29	1.13	1.06	0.57	0.88	1.72	0.96	0.76	0.92	1.13	0.91	0.98
Other SW	0.35	0.58	0.45	0.46	0.80	0.80	1.10	0.87	0.54	0.49	0.77	0.57	0.63
WEEE[a]	0.04	0.06	0.15	0.07	0.06	0.09	0.16	0.09	0.03	0.25	0.18	0.15	0.1
Batteries[a]	0.01	0.02	-	0.01	0.05	0.00	0.04	0.03	0.15	0.05	0.04	0.09	0.04
Refuse waste	2.96	2.10	3.47	2.75	3.63	4.93	5.14	4.47	6.11	6.40	5.76	6.14	4.45
SHHW	7.65	14.19	15.80	12.02	9.87	10.13	11.22	10.28	10.82	9.58	9.94	10.15	10.82
Average HWGR	0.3108	0.4205	0.3541	0.3624	0.3651	0.4399	0.3553	0.3911	0.4358	0.4336	0.4959	0.4489	0.4008
Average HH per day	32.85	33.42	16.85		30.43	32.57	16.71		26.57	31.86	15.57		
Average people per day	119.00	96.85	63.28		96.28	99.85	56.57		85.14	93.71	47.57		

Table 5. Waste generation per category. Mean, standard deviation, 95% confidence interval (Inferior and Superior Limits; IL, SL) and r coefficient of Q-Q plots for each generation rate results distribution.

	High SES (all values in kg/person/day)					**Medium SES** (all values in kg/person/day)					**Lower SES** (all values in kg/person/day)				
	mean	sd	IL (95%)	SL (95%)	rQ-Q plot	mean	sd	IL (95%)	SL (95%)	rQ-Q plot	mean	sd	IL (95%)	SL (95%)	rQ-Q plot
Organic waste	0.199	0.029	0.186	0.212	0.979	0.227	0.030	0.213	0.240	0.990	0.223	0.074	0.189	0.257	0.939
Gardening waste[a]	0.005	-	-	-		0.021	-	-	-		0.006	-	-	-	
Paper	0.020	0.004	0.018	0.022	0.993	0.016	0.006	0.014	0.019	0.986	0.016	0.008	0.012	0.020	0.970
Board	0.012	0.005	0.010	0.015	0.967	0.012	0.004	0.010	0.014	0.988	0.010	0.004	0.009	0.012	0.921
PET	0.008	0.003	0.006	0.009	0.978	0.008	0.002	0.007	0.009	0.954	0.007	0.003	0.006	0.008	0.981
HDPE	0.002	0.001	0.001	0.003	0.981	0.002	0.001	0.002	0.003	0.970	0.003	0.003	0.002	0.005	0.958
Other plastics	0.029	0.005	0.027	0.031	0.987	0.029	0.005	0.027	0.031	0.975	0.028	0.009	0.024	0.032	0.920
Glass	0.029	0.020	0.019	0.038	0.927	0.027	0.015	0.020	0.034	0.953	0.022	0.012	0.016	0.027	0.948
Textiles	0.004	0.004	0.003	0.006	0.927	0.007	0.005	0.005	0.009	0.971	0.007	0.005	0.005	0.010	0.937
Aluminium[b]	0.001	0.001	0.001	0.002	0.985	0.001	0.001	0.001	0.001	0.916	< 0.001	-	-	-	-
Ferrous metals	0.004	0.002	0.003	0.004	0.974	0.003	0.002	0.002	0.004	0.981	0.004	0.003	0.003	0.006	0.967
Tetra brik	0.003	0.001	0.002	0.003	0.955	0.004	0.001	0.004	0.005	0.978	0.006	0.003	0.004	0.007	0.967
Other SW	0.002	0.002	0.001	0.003	0.962	0.003	0.002	0.002	0.004	0.960	0.003	0.003	0.002	0.004	0.942
WEEE[a]	< 0.001	-	-	-	-	< 0.001	-	-	-	-	0.001	-	-	-	
Batteries[a]	< 0.001	-	-	-	-	< 0.001	-	-	-	-	< 0.001	-	-	-	
Refuse waste	0.017	0.011	0.012	0.022	0.915	0.020	0.013	0.014	0.026	0.937	0.019	0.009	0.015	0.023	0.994
SHHW	0.036	0.015	0.029	0.042	0.971	0.050	0.021	0.041	0.060	0.924	0.046	0.027	0.033	0.058	0.932
Average HWGR	0.371	0.067	0.340	0.401	0.969	0.431	0.061	0.403	0.459	0.954	0.402	0.100	0.357	0.448	0.948

[a] Results of the HWGR not normally distributed in all strata

[b] Results of the HWGR not normally distributed only for Low SES

The average HWGR for the three sampling campaigns is 0.4008 kg/person/day, which is similar to results of several studies focusing on households from DC. For Mexico, Buenrostro and Israde (2003) reported an average HWGR of 0.405 kg/person/day for 8 municipalities, while Bernache-Pérez et al. (2001) reported 0.51 kg/person/day for Guadalajara. Miezah et al. (2015) obtained, for municipalities of Ghana, a HWGR of 0.4 kg/person/day. Byamba and Ishikawa (2017) report a HWRG of 0.47 kg/person/day for Ulaanbaatar, and Khan et al. (2016) found a HWGR of 0.41 kg/person/day for the district of Dhanbad, in India. Xu et al. (2016) analysed waste generation rates of households in Xiamen Island, China, and found a lower value of 0.31 kg/person/day, whereas Parizeau et al. (2006) reported 0.34 kg/person/day for Cambodia. For Nepal, Dangi et al. (2011, 2013) report 0.33 kg/person/day for Tulsipur and 0.49 kg/person/day for Kathmandu Metropolitan City.

Other studies in developing countries found higher values for HWGR average. Ojeda-Benítez et al. (2008) reported for the city of Mexicali an average HWGR of 0.98 kg/person/day. This difference may be explained by the fact that, in their sampling procedure, "[o]nly family units or households that provided a minimum of five 48-gal plastic bags containing the solid waste generated on a daily basis were included" (Ojeda-Benítez et al., 2008, p. 995).

3.4 Comparison between strata and data quality

In order to compare strata, we first calculated the daily HWGR of each waste category (e.g. organic waste in kg/person/day, based on data corresponding to 21 days of work) and the daily average of total HWRG, for each stratum. Then, we analysed the normality of data associated to each category through a Shapiro-Wilks test. The test results showed that the hypothesis of normality should be discarded only for gardening waste, WEE and batteries for the High and Medium SES, whereas in the case of Low SES, the hypothesis should also be discarded for the category aluminium. All other generation rates of individual waste categories were normally distributed in the three strata. The Q-Q plots of main waste categories are shown in Figure SI.2 of the Supplementary Information. The r value of each Q-Q plot is included in Table 5.

Table 5 summarizes, for each stratum, the mean values, standard deviations, and confidence intervals (95% confidence level) for the normally distributed fractions and for the average HWGR. With respect to HWGR average, our results are consistent with the findings of other studies about the higher generation rate in the Medium SES group (Khan et al., 2016; Ojeda-Benítez et al., 2008). When analysing in which categories the generation rate in Medium stratum is higher, we observed a clear difference for the gardening waste. This may be due to housing or behavioural specificities associated to this stratum.

We carried out an ANOVA and Tukey test for each normally distributed HWGR fraction in order to compare strata. Only one category -tetra brik- showed a significant statistical difference for High SES, where HWGR is lower than in the other strata. This absence of significant difference between strata is consistent with results of other studies (Gomez et al., 2008; Khan et al., 2016; Miezah et al., 2015; Xu et al., 2016).

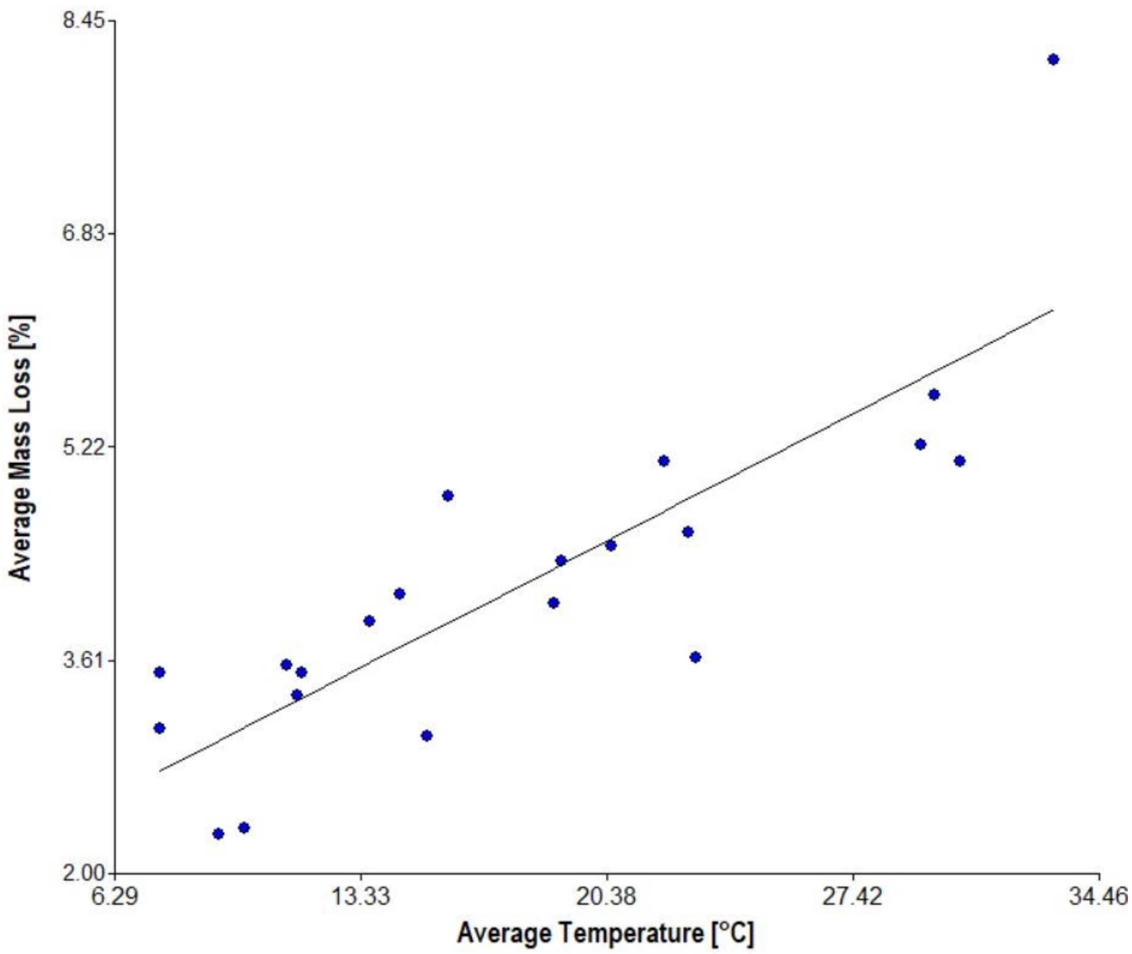
3.5 Mass losses and moisture content: the singularity of yerba mate?

Mass losses were calculated daily for each stratum as the difference between the weight of the waste when entering the process of coning and quartering and the sum of the weights of all sorted fractions. The average mass loss -in percentage- and its standard deviation (sd) for each campaign were as follows: 3,12 (sd = 0.86), for the end of autumn; 5,40 (sd = 1.72), for the end of spring; 3,76 (sd = 0.67), for the beginning of the autumn.

These values are high when compared with the 1,7% reported by Edjabou et al. (2015) and with the maximum of 3% allowed by the standard of waste composition analysis from the Austrian Standards Institute (Lebersorger and Schneider, 2011). The main source of these values may be the loss of moisture of the waste (evaporation) during its processing. Evaporation is affected by temperature, wind speed, and the air humidity. Since wind speed and air humidity are strictly local phenomena and where not measured, we asked the hourly temperature records of Tandil for the 21 days of characterization to the National Meteorological Service. We computed the daily average temperature for the hours in which the work was performed (12 hs – 17 hs) and plotted it against the average mass loss of the day (see Figure 2). A determination coefficient r^2 of 0.7 was obtained.

This important loss may be also associated with a very singular habit of the South American region: the consumption of yerba mate infusion. Mate is a hot infusion prepared with the dried and finely ground leaves and twigs of the ilex paraguariensis St. Hilaire tree (normally in particles of less than 3 mm and up to 35% in form of powder). Mate is prepared in a calabash or metal gourd and drunk with a metal straw. After its use, the used (wet) yerba is usually thrown away with mixed waste.

Figure 2. Regression analysis plot of the average mass loss [%] of each day (three daily measures, one for each strata) and the average temperature registered during of the working hours of the day (12 -17 hs). Source: our study and the Meteorological Information Centre of the National Meteorological Service of Argentina.



The Yerba Mate National Institute statistics *(INYM, 2018)* states an average consumption of 6 kg/person/year of yerba mate, which represents a significant amount of related waste considering that once used, i.e., wet, the yerba residue triples the weight of the dried yerba (Gullón et al., 2018). In terms of waste, this means that an average of 18 kg/per/year are generated, of which 2/3 is water.

When compared with the ~320 kg/person/year of MSW arriving to the landfill (see supplementary information), this amount of waste represents ~6%. Assuming that the overall composition of MSW is similar to that of the HHW with about 53% of organics (~170 kg/per/year), it could be more than 10% of this fraction which may be due to the consumption of yerba mate.

This is consistent with the experience we had during the picking analysis, where yerba mate was really abundant and adhered to other materials, losing its moisture fast when dispersed.

4. Conclusions

The characterization of solid waste carried out in Tandil shed light on the composition and amount of waste generated in households. An average of more than 80 households stratified according to three distinct socioeconomic status (High, Medium and Low SES) participated in the study. Each sampling campaign took place during one week: in late autumn 2016, in late spring 2016, and in early autumn 2017. It was the first door-to-door characterization of solid waste in Tandil.

Organic waste was the higher fraction in each stratum, representing more than half of the total generated waste. High mass loss during waste analysis was constantly measured. This may indicate that the organic fraction had an important moisture content. Preliminary research based on market information indicates that yerba mate waste is an important contributor of organic matter in Argentina and probably also in other southern countries of Latin America. Further research would better assess the role of yerba mate waste in the local context.

While overall composition of waste remained mainly stable during the three sampling campaigns, household waste generation rate (HWGR) increased steadily. The average HWRG was 0.4008 kg/person/day, the lowest value of the first sampling campaign (0.3618 kg/person/day) and the higher of the last one (0.4506 kg/person/day). This difference may be explained by the lower consumption rates of 2016 in Argentina, and the subsequent economic recovery of 2017. According to these values, households contribute less than 50% to the overall MSW landfilled. Further research is needed to know the amount and composition of household waste generated in other sources.

Medium SES stratum showed the higher average HWRG: *0.4314 kg/person/day*. Per capita generation rates by category of waste and stratum were analysed in their normality, results showing that most of them were normally distributed. This information was used to compare strata. However, no statistically significant differences were found. This may be related to the high degree of urbanization of the sampling zone despite SES differences *(Xu et al., 2016)*. Complementary qualitative research is needed to better understand these aspects.

Further research is needed to find a procedure of waste analysis adequate to the characteristics of local waste. Moisture and yerba mate contamination of dry materials, mostly paper and board, were not measured but may be relevant. A procedure of sieving or drying and sieving could be suitable to improve data quality, but budget constraints make these methods unfeasible. Alternately, a separate collection of wet and dry waste for waste analysis may be adequate to lower contamination, but this would require supplementary efforts of people participating in the study.

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Supplementary Information

Table SI.1: Landfilled MSW for the period 2010-2015 and daily average per capita.

	2010	2011	2012	2013	2014	2015
Yearly landfilled MSW [metric tonnes]*	36201	36672	37105	40519	42393	44058
Inhabitants**	124631	126170	127689	129214	130718	132199
Average MSW Landfilled Rate*** [kg/person/day]	0.7957	0.7963	0.7961	0.8591	0.888	0.9131

* MSW collected by compactor trucks, i.e. a mix of household and commerce waste for the Tandil County, including 2 neighbouring villages of Tandil city (information provided by the operator of the landfill). ** Inhabitants of the Tandil County: for 2010, data from national population census; for next years, its projection (INDEC, 2015b). *** Computed as Yearly landfilled MSW*1000/365/inhabitants

SI – Planning of the sampling

The planning phase was aimed to find a balance between the ambition for information and the availability of resources. The workforce was composed of graduate and last year undergraduate Diagnostic and Environmental Management students from the local University, and researchers. A total of 30 persons were concerned during the eight days of the operational phase of each campaign, an average of 5-7 persons classifying waste each day.

Students received several training sessions regarding WM and MSW characterization studies. We put special emphasis on the instructions to follow at the recruitment of HH, as students should be able to communicate the importance of the study, its anonymous nature and the fact that all daily generated waste -even recyclables- should be put in the plastic bags provided by the organizers.

Sensitivity analysis for determination of the number of samples

As mentioned in Section 2.3.1 of the main article, we applied the Equation 1 to calculate the number of samples needed in our study.

$$n = s^2/[(ex/1.96)^2 + s^2/N] \qquad [1]$$

where s is standard deviation of HWGR; e is the allowed error for the estimation (in percentage) of the HWGR and x is its mean value; N is the total number of households (population)

Based on the information presented in Table SI.1 and the literature review, we estimated a HWGR within the range [0.375–0.8] kg/person/day. Then, we performed a sensitivity analysis conducted to evaluate how the required number of samples varied according to different values of the HWGR mean, the percentage of error and the standard deviation. It consisted of: 1) the choice of three possible values for each of these variables, for a fixed confidence level of 95%; 2) the application of Equation 1 for all possible combinations.

Table SI.2 presents this information. For the HWGR mean, we evaluated both extremes and a medium value of the determined range. For the standard deviation and the error percentage, we adopted values suggested by Sakurai *(1983)* as medium values and we applied +/- 50% for high/low adopted values.

Table SI.2: Sensitivity analysis of the number of samples required for changing values of sampling error, mean of Household Waste Generation Rate (HWRG) and its standard deviation

	Standard deviation		
HWGR	Low [0.1 kg]	Medium [0.2 kg]	High [0.3 kg]
Error = 5%			
Low [0.375 kg/pers/day]	109	433	962
Medium [0.65 kg/pers/day]	36	145	325
High [0.8 kg/pers/day]	24	96	215
Error = 10%			
Low [0.375 kg/pers/day]	27	109	244
Medium. [0.65 kg/pers/day]	9	36	82
High [0.8 kg/pers/day]	6	24	54
Error = 15%			
Low [0.375 kg/pers/day]	12	49	109
Medium [0.65 kg/pers/day]	4	16	36

High [0.8 kg/pers/day]	3	11	24

We see how the number of samples is higher as the desired error is lower. Moreover, when the weight of the standard deviation over the mean is higher, so is the number of samples required.

Determination of socioeconomic strata using GIS

Because there is no income data retrieve in the Argentinian national census, to stratify the HH of Tandil in socioeconomic strata (SES) we selected 14 variables related to educational, social and housing conditions[69]. Then, we used the Grouping Analysis tool of ArcGIS to group census blocks in three levels according to their characteristics in relation to the defined variables.

Table SI.3 presents the average, standard deviation, minimum and maximum values of each variable, for the three SES created through the Grouping Analysis tool of ArcGIS. Figure SI.1 presents a standardized version of this data for each variable, in the form of a box-plot. On the graph, we can distinguish the three SES with different colours.

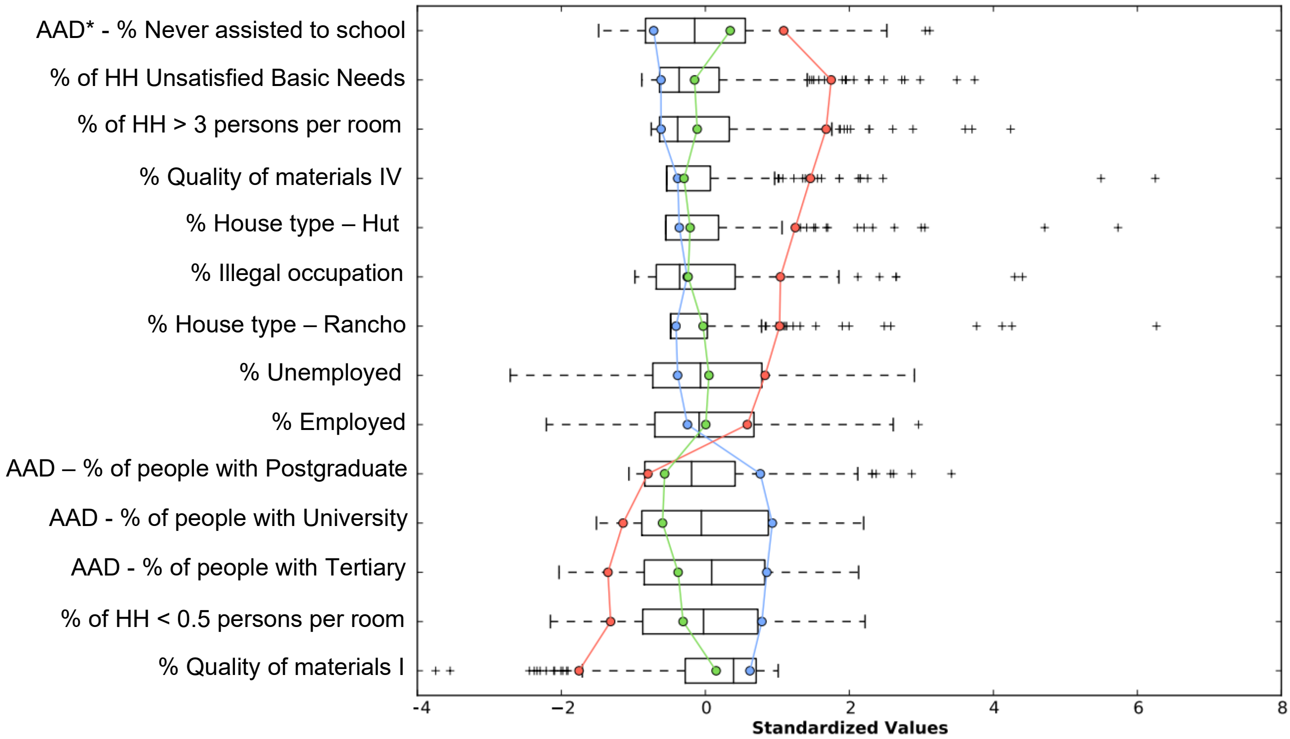
We can see that the variables that better differentiate the three SES are those related to the achieved academic degree. Moreover, we see that in most of other variables, High and Medium SES strata are next to each other, while a marked difference exist between them and the Low SES.

[69] CALMAT I and CALMAT IV refer to the quality of the constituent materials of the house/department. CALMAT I is assigned when the building has strong and solid materials in all constituent components (floors, walls and ceilings) and incorporates all the elements of insulation and finish. CALMAT IV is assigned when at least one principal component is built with non-resistant materials (but not all of them).

Table SI.3. Results of the Grouping Analysis performed by ArcGIS. Source: Based on the ArcGIS Grouping Analysis report.

	High Socioeconomic Status				Medium Socioeconomic Status				Low Socioeconomic Status			
Variable	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
% Illegal HH occupation	**0.9956**	1.038	0	4.6632	**1.0141**	0.8993	0	3.6545	**2.7744**	1.7995	0	7.3892
% of HH with less than 0.5 persons per room	**37.7804**	7.7826	16.9811	54.1254	**25.2985**	6.4751	13.986	41.8605	**13.8243**	4.1705	4.2895	22.6519
% of HH with more than 3 persons per room	**0.3589**	0.4278	0	1.7544	**1.6873**	1.1588	0	5.1546	**6.421**	2.7198	1.7699	13.1944
% Index of the quality of materials IV (CALMAT IV)	**0.1164**	0.2532	0	1.1905	**0.1834**	0.2475	0	1.1792	**1.5219**	1.1083	0	5.1724
% Index of the quality of materials I (CALMAT I)	**95.2552**	3.3814	82.2785	100	**89.5785**	5.9084	73.4375	98.1818	**66.5303**	9.0077	42.446	81.1475
% House type – Hut	**0.0945**	0.2486	0	1.3514	**0.1711**	0.2414	0	1.0554	**0.9134**	0.7668	0	3.1915
% House type – Rancho	**0.0639**	0.1958	0	1.0204	**0.3842**	0.6065	0	2.5271	**1.2895**	1.3998	0	5.7471
% of HH with Unsatisfied Basic Needs	**0.962**	0.7704	0	3.5714	**2.644**	1.5739	0	7.5601	**9.4854**	3.1308	3.7234	16.6667
% Employed	**63.4458**	5.145	53.6585	77.7202	**64.7153**	4.9725	55.9677	79.4712	**67.5955**	3.0952	57.0156	73.0375
% Unemployed	**3.1031**	1.0506	0.5917	5.6926	**3.5733**	0.8617	1.7606	6.3391	**4.4143**	0.9324	2.6726	6.6556
Academic achieved degree – % of people with Postgraduate	**1.9183**	0.9849	0.3656	4.7081	**0.5215**	0.3845	0	1.7544	**0.2778**	0.5303	0	2.3973
Academic achieved degree – % of people with University	**24.9429**	5.2176	14.3174	37.3089	**10.0848**	4.187	3.1469	19.1388	**4.7431**	4.0717	1.1356	20.2055
Academic achieved degree – % of people with Tertiary	**12.5035**	1.6373	8.5595	17.1171	**8.0517**	2.1809	3.9106	13.4921	**4.5289**	1.7421	2.0737	8.744
Academic achieved degree – % of people that Never assisted to school	**0.5598**	0.4539	0	2.8513	**1.3393**	0.5169	0.3431	3.3248	**1.8837**	0.6382	0.6803	3.3708

Figure SI.1. Box-plot of each selected census variable. In blue, High SES; in green, Medium SES; in red, Low SES. Source: Based on the ArcGIS Grouping Analysis report.



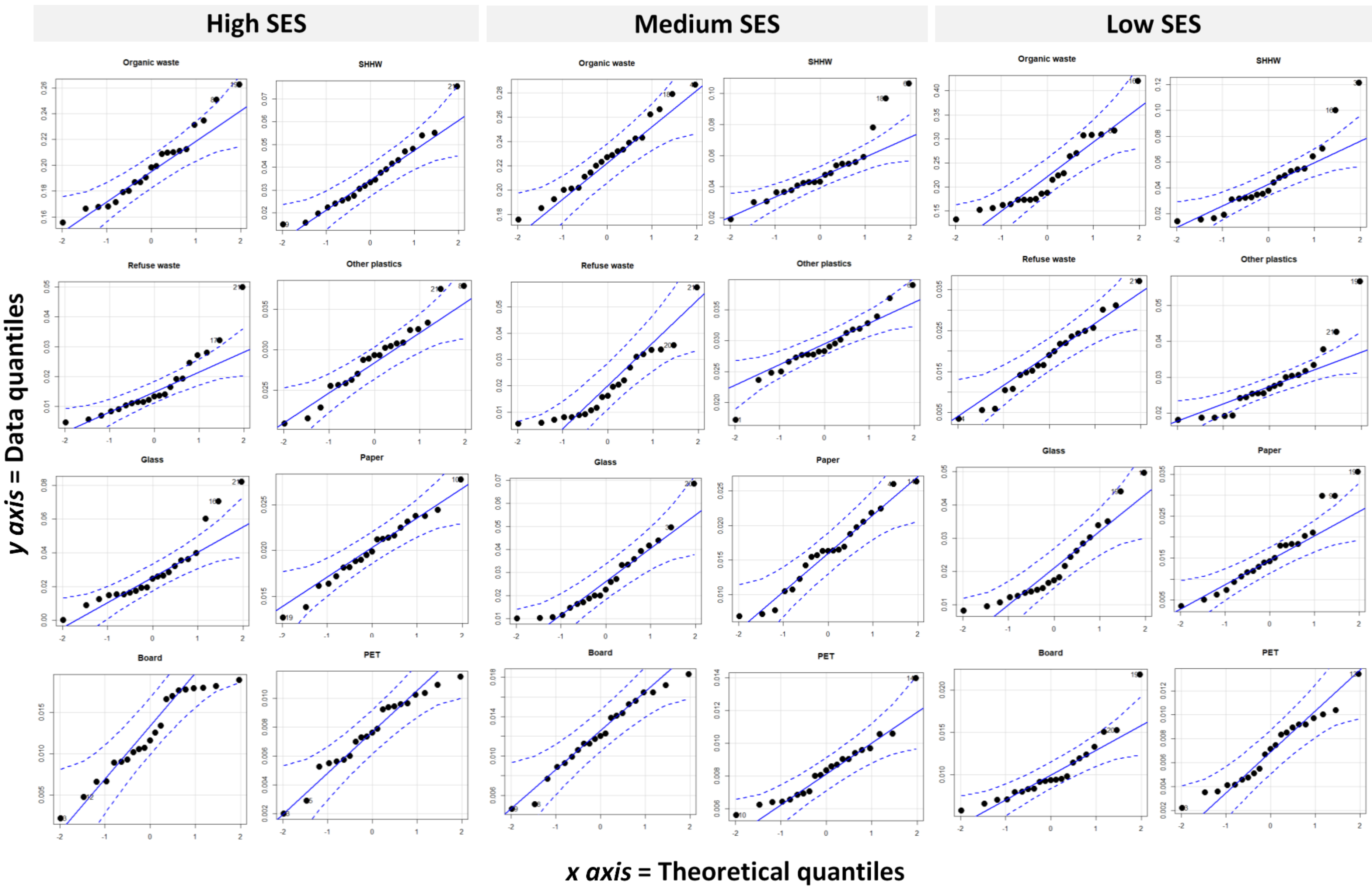
*AAD = Academic achieved degree

SI - Results

Q-Q Plots of the main waste fractions

Figure SI.2 shows the Q-Q plots of the main waste fractions. r coefficients for all normal-distributed categories Q-Q plots are shown in Table 5 of the main article.

Figure SI.2. Q-Q plots of main waste categories in kg/person/day. Plotted data corresponds to 21 measures, one for each characterization day



Research Data (also available online)

Cam-paign	Day	Strata	Organic waste	Gardening waste	Paper	Board	PET	HDPE	Other plastics	Glass	Tex-tiles	Alumi-nium	Ferrous metals	Tetra brik	Other SW	WEE	Batte-ries	Refuse waste	Phatogenic waste	Daily Total Waste	Parti-ipants	HWGR
M1	D1	High	21.079	0	1.912	1.567	1.13	0.151	3.07	3.329	0.313	0.047	0.284	0.272	0.261	0	0	0.668	1.822	35.905	117	0.306880342
M1	D2	High	22.179	0	1.82	1.179	0.97	0.185	3.867	3.425	0.696	0.238	0.621	0.258	0.13	0	0	0.907	2.956	39.431	132	0.298719697
M1	D3	High	24.107	0.573	2.279	0.264	0.244	0.195	2.767	1.083	0.299	0	0.482	0.612	0.054	0	0	1.014	2.895	36.868	121	0.304694215
M1	D4	High	21.93	0	3.046	2.329	0.72	0.124	3.867	3.15	0.043	0.03	0.583	0.292	0.094	0	0.023	1.552	3.371	41.154	128	0.321515625
M1	D5	High	20.779	0	2.419	1.33	0.36	0.172	3.167	2.029	0.257	0.013	0.51	0.236	0.036	0	0	0.58	3.155	35.043	124	0.282604839
M1	D6	High	18.279	0	2.334	0.73	0.77	0.303	2.817	4.36	0.471	0.275	0.082	0.144	0.255	0.098	0	1.541	2.158	34.617	110	0.3147
M1	D7	High	19.234	0	2.339	1.679	0.531	0.132	3.117	1.964	0.211	0.144	0.61	0.237	0.07	0	0	1.375	3.373	35.016	101	0.346693069
M2	D1	High	25.85	0	2.45	1.75	0.95	0	3.9	2.708	0.44	0.182	0.198	0.446	0.273	0	0.047	1.144	4.952	45.29	103	0.439708738
M2	D2	High	18.9	4.847	1.45	0.812	0.85	0.236	2.6	1.373	0.229	0.06	0.397	0.063	0.284	0.119	0	0.928	1.34	34.488	90	0.3832
M2	D3	High	22.9	0	2.75	1.75	0.95	0.184	3.3	3.183	0.165	0.162	0.162	0.099	0.409	0.01	0	1.138	4.112	41.274	99	0.416909091
M2	D4	High	18.45	0	1.869	1.847	0.75	0.342	2.15	1.779	1.269	0.121	0.438	0.202	0.132	0	0.073	1.379	4.034	34.835	103	0.338203883
M2	D5	High	15.55	0	2.25	0.475	0.6	0.259	2.15	1.917	0.067	0.134	0.139	0.25	0.32	0.028	0	0.9	4.314	29.353	100	0.29353
M2	D6	High	17.2	0.13	2.25	0.852	0.7	0.299	2.8	1.144	0.853	0.129	0.133	0.123	0.227	0	0	1.78	2.9217	31.5417	92	0.342844565
M2	D7	High	17.25	0.555	1.85	0.917	0.9	0.047	2.5	0.011	0.334	0.186	0.325	0.216	0.317	0	0	1.673	2.655	29.736	87	0.341793103
M3	D1	High	18.7	0	1.749	1.665	0.9	0.313	2.85	1.308	0.538	0.16	0.387	0.237	0.092	0	0	1.006	4.749	34.654	88	0.393795455
M3	D2	High	18.35	0	1.651	0.884	0.95	0.4	2.55	6.133	0.471	0.204	0.175	0.156	0.032	0	0	2.141	2.995	37.092	87	0.426344828
M3	D3	High	18.15	0.827	1.578	0.575	1	0.224	2.25	5.233	0.505	0.1	0.302	0.246	0.057	0	0	2.791	3.27	37.108	87	0.426528736

M3	D4	High	21.35	0	1.563	1.142	0.5	0.016	2.8	3.283	0.004	0.065	0.345	0.449	0.492	0	0.326	1.503	4.272	38.11	91	0.418791209
M3	D5	High	22.85	3.4	1.101	1.564	0.5	0.146	2.35	1.333	0.221	0.113	0.354	0.253	0.17	0.089	0	2.36	4.792	41.596	87	0.478114943
M3	D6	High	14.95	0	1.713	0.928	0.75	0.4	2.6	2.833	0.108	0.147	0.398	0.249	0.424	0	0	2.241	2.202	29.943	80	0.3742875
M3	D7	High	15.95	0	1.644	1.351	0.6	0.123	2.85	6.233	1.003	0.193	0.478	0.383	0.131	0	0.057	3.791	5.74	40.527	76	0.53325
M1	D1	Low	17.08	0	0.894	0.929	0.309	0.364	2.067	3.726	0.679	0.024	0.123	0.212	0.178	0.074	0	1.42	4.113	32.192	75	0.429226667
M1	D2	Low	14.779	0	0.799	0.549	0.286	0.215	1.667	0.96	0.597	0	0.088	0.128	0.021	0	0	1.142	2.123	23.354	69	0.338463768
M1	D3	Low	10.841	1.436	0.87	0.41	0.128	0	1.417	1.649	0.236	0.161	0.127	0.328	0.069	0	0	0.323	7.043	25.038	58	0.431689655
M1	D4	Low	10.029	0	0.745	0.53	0.275	0.101	1.117	1.967	0.409	0.023	0.302	0.109	0.008	0	0	0.201	2.191	18.007	58	0.310465517
M1	D5	Low	10.18	0	1.327	0.412	0.42	0.024	1.179	1.536	0.248	0	0.065	0.226	0.045	0.021	0	1.383	3.323	20.389	63	0.323634921
M1	D6	Low	9.679	0	1.056	0.544	0.323	0.157	1.767	0.722	0.248	0.159	0.565	0.565	0.061	0.065	0	0.344	4.155	20.41	59	0.345932203
M1	D7	Low	9.28	0	1.818	0.429	0.311	0	1.717	0.58	0.845	0.027	0.044	0.219	0.323	0.069	0	0.655	1.966	18.283	61	0.299721311
M2	D1	Low	16.8	0	0.493	0.704	0.55	0.105	1.767	1.598	0.126	0.034	0.34	0.662	0.295	0	0	1.359	1.828	26.661	53	0.503037736
M2	D2	Low	7.4	0	1.673	0.522	0.5	0.122	1.05	1.963	0.05	0.023	0.18	0.316	0.046	0.09	0.014	0.581	1.985	16.515	56	0.294910714
M2	D3	Low	10.3	0	0.821	0.674	0.27	0.527	1.5	0.878	1.363	0.095	0.183	0.408	0.521	0.007	0	1.176	0.971	19.694	59	0.33379661
M2	D4	Low	11.15	1.082	1.081	0.715	0.5	0.207	1.15	0.809	0.294	0.037	0.102	0.226	0.085	0	0	0.91	3.868	22.216	60	0.370266667
M2	D5	Low	9.35	0.07	0.569	0.506	0.193	0.501	1.45	0.778	0.259	0.073	0.22	0.268	0.158	0	0.016	0.794	2.381	17.586	54	0.325666667
M2	D6	Low	9	0	0.294	0.334	0.777	0.22	1.05	0.619	0.608	0.019	0.231	0.337	0.141	0.124	0.024	0.954	1.829	16.561	58	0.285534483
M2	D7	Low	9.7	0.32	0.413	0.468	0.4	0.169	1.7	1.212	0.692	0.037	0.338	0.185	0.281	0	0	1.391	2.766	20.072	56	0.358428571
M3	D1	Low	10.502	0.648	0.295	0.389	0.165	0.188	1.2	0.856	0.07	0	0.458	0.29	0.106	0.003	0.006	0.663	1.527	17.366	47	0.369489362
M3	D2	Low	20.6	0	0.173	0.466	0.475	0.137	1.85	1.282	0.479	0.042	0.234	0.385	0.414	0	0	1.527	4.908	32.972	49	0.672897959
M3	D3	Low	14.5	0	0.666	0.708	0.35	0	1.2	0.778	0.107	0.019	0.013	0.288	0.015	0	0.049	1.02	2.542	22.255	47	0.473510638
M3	D4	Low	15.1	0	0.9	0.48	0.45	0.164	1.5	0.618	0.353	0.019	0.268	0.244	0.151	0.13	0	1.19	2.347	23.914	49	0.488040816
M3	D5	Low	12.15	1.104	1.601	0.983	0.45	0.273	2.55	1.983	0.297	0.02	0.465	0.355	0.018	0.515	0.012	1.355	0.855	24.986	45	0.555244444
M3	D6	Low	15.047	0.653	0.897	0.749	0.45	0.128	1.55	0.4	0.195	0.054	0.244	0.249	0.382	0.054	0	1.15	0.749	22.951	49	0.468387755

M3	D7	Low	12.371	1.029	0.952	0.373	0.4	0.312	2	0.813	0.537	0.018	0.219	0.302	0.221	0.135	0	1.741	0.661	22.084	47	0.46987234
M1	D1	Med	24.22	0	0.718	1.229	0.97	0.629	1.717	2.001	0.079	0.113	0.418	0.605	0.112	0.085	0	0.587	5.481	38.964	100	0.38964
M1	D2	Med	24.779	0	1.671	1.68	0.67	0.316	2.817	2.761	0.227	0.206	0.268	0.522	0.098	0.058	0.023	0.569	4.364	41.029	102	0.402245098
M1	D3	Med	22.23	0	2.138	1.038	0.92	0.268	2.667	4.862	0.048	0	0.411	0.589	0.651	0	0	0.687	4.778	41.287	98	0.421295918
M1	D4	Med	27.23	0	2.468	0.879	0.67	0.078	2.967	3.957	0.053	0	0.008	0.494	0.113	0	0	0.876	7.42	47.213	95	0.496978947
M1	D5	Med	21.023	0	2.199	1.53	0.84	0.152	2.767	3.502	0.055	0.154	0	0.296	0.238	0	0	1.047	5.358	39.161	98	0.399602041
M1	D6	Med	19.849	0.184	1.452	1.529	0.57	0	3.467	2.307	1.084	0.04	0.347	0.531	0.259	0.027	0.023	1.441	9.475	42.585	89	0.478483146
M1	D7	Med	17.78	1.512	1.893	1.379	0.92	0.238	2.267	2.172	0.635	0.031	0.217	0.635	0.184	0	0	0.772	3.475	34.11	96	0.3553125
M2	D1	Med	20.2	1.7	1.05	0.509	0.8	0.379	2.9	3.333	1.464	0.068	0.262	0.296	0.217	0.14	0	1.957	5.897	41.172	100	0.41172
M2	D2	Med	25.05	9.65	1.589	0.433	0.85	0.3	3	1.092	0.257	0.242	0.432	0.283	0.497	0.023	0	1.912	3.83	49.44	94	0.525957447
M2	D3	Med	22.4	2.7	1.05	0.75	0.55	0.109	2.95	1.033	1.154	0.035	0.268	0.701	0.406	0.026	0.009	1.139	4.649	39.929	98	0.407438776
M2	D4	Med	23.4	0.151	1.895	1.85	0.7	0.294	2.85	1.724	1.119	0.063	0.192	0.313	0.182	0.052	0	3.133	4.266	42.184	101	0.417663366
M2	D5	Med	21.8	5.15	1.683	1.223	1.15	0.25	2.7	4.283	0.938	0.034	0.75	0.415	0.419	0	0	0.969	4.089	45.853	109	0.420669725
M2	D6	Med	24.25	1.523	1.481	1.03	1.1	0.407	3.3	1.069	0.981	0.05	0.563	0.414	0.354	0	0	3.495	3.115	43.132	104	0.414730769
M2	D7	Med	24.4	0.201	2.45	1.309	1.3	0.338	3.05	1.858	0.882	0.169	0.443	0.285	0.364	0.026	0	2.497	5.19	44.762	93	0.481311828
M3	D1	Med	17.75	2.704	2.072	0.897	0.65	0.169	2.8	1.486	1.291	0.019	0.129	0.208	0.008	0	0.119	0.807	4.35	35.459	101	0.351079208
M3	D2	Med	17.9	0	0.719	1.116	0.75	0.268	3.15	3.083	0.212	0.03	0.183	0.227	0.21	0.004	0	2.041	3.984	33.877	93	0.364268817
M3	D3	Med	19.3	3.35	1.563	1.079	0.6	0.17	2.4	1.56	0.539	0.044	0.166	0.423	0.103	0	0	3.241	1.817	36.355	96	0.378697917
M3	D4	Med	25.65	3.801	1.515	1.514	0.8	0.207	2.55	4.033	0.721	0.043	0.37	0.492	0.245	0	0	1.436	8.918	52.295	92	0.568423913
M3	D5	Med	20.9	0	0.654	1.114	0.65	0.159	3.5	1.783	0.218	0.086	0.232	0.27	0.089	0	0.024	3.041	5.098	37.818	95	0.398084211
M3	D6	Med	17.5	0.281	1.016	1.15	0.75	0	2.45	5.683	0.546	0.257	0.163	0.405	0.04	0.105	0	2.941	2.537	35.824	83	0.431614458
M3	D7	Med	22.94	9.06	1.506	1.464	0.8	0.156	2.55	0.968	1.826	0.088	0.676	0.384	0.697	0.048	0	5.511	3.495	52.169	96	0.543427083

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Article 2: Material Flow Analysis (MFA) and waste characterizations for formal and informal performance indicators in Tandil, Argentina: decision-making implications

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Abstract

In cities, the achievement of waste-related legal requirements and the main drivers of Integrated Sustainable Waste Management (ISWM) need adequate indicators and adaptable-to-case tools and strategies. In this work, we combine Material Flow Analysis (MFA) and waste characterizations to develop a mass balance table to design, calculate and analyse indicators related to the formal and informal waste sub-circuits of Tandil, a medium-sized city of the Buenos Aires province (Argentina). Results show that global recovery is very low (2.3% ± 0.16) and mainly driven by the Informal Recovery Sector (IRS). Also, the IRS strategy is more effective, recovering 40% ± 8.0 of its targeted materials from non-household sources. Regarding each material recovery performance, results show significant differences. For paper and board, recovery exceeds 20%. For HDPE, Tetra brik and Ferrous Metals are lower than 1%. In the case of PET and Glass, 9.6 and 9.0 % of what is generated in households is recovered, respectively. However, the global recovery rate of each material is different: 2.9% ± 0.4 for PET and 5.5% ± 1.4 for Glass. Our research shows that strategies in place are insufficient regarding legislation in force. Even a hypothetically 100% effectiveness in them will account only for 20.9% ± 2.1 of global recovery. Addressing organic waste, therefore, is imperative. Considering the current province law provision of final disposal diversion, accounting for the work of the IRS is key because they recover more waste than the official strategy. Regarding open dumps eradication, we estimate that up to 17% of generated waste is incorrectly final disposed through private skips illegally dumped. A tracking system for skips could avoid this situation.

Highlights

- We use Material Flow Analysis and characterizations data to calculate indicators
- Adequate data allows us to quantify generation by source and category of waste
- The informal sector recovers more tons and is more effective in doing so
- Strategies in place are inadequate to respond to current legal requirements
- Private skips need regulation for better landfill use and to prevent open dumping

Keywords
Material Flow Analysis

Recovery indicators

Generation by source

Informal recycling Sector (IRS)

Buenos Aires province

1. Introduction

From the Agenda 21 (United Nations, 1992) to the 2030 Agenda (United Nations, 2015), waste management (WM) has been recognized as a critical component of sustainable development. However, relatively recent changes, such as the increased complexity of materials and goods (Singh et al., 2014), the massive use of Electric and Electronic Equipment (Baldé et al., 2017), and the exponential growth of waste generation rates (UNEP and ISWA, 2015), among others, have deepened the concern about achieving a global circular economy (Geng et al., 2019; Stahel, 2016), in which waste management plays a key role (European Commission, 2015).

Beyond general considerations though, waste management remains a local issue, facing non-standardized governance and technical challenges related to the main drivers of an Integrated Sustainable Waste Management (Scheinberg et al., 2010b; Stanisavljevic and Brunner, 2014; Wilson et al., 2015): the protection of public health and the environment, the management and recovery of resources (3Rs), and the no export of problems to the future (after-care free landfills). Measuring the achievement of these goals and its evolution through adequate indicators needs the implementation of adaptable-to-case tools and strategies (Aljerf and Choukaife, 2016).

Waste process flow diagrams (PFD) are, in this sense, considered as a powerful tool (Scheinberg et al., 2010b; UNEP and ISWA, 2015; Wilson et al., 2012) because they allow to represent the main structure of the WM system (WMS) in a simple but comprehensive way (Scheinberg et al., 2010b). They consist of identifying processes related to waste (generation, transportation, treatment, disposal, etc.) and flows that connect them within a defined system, and the flows that enter and leave the boundaries of the waste management system (WMS), which are generally the spatial boundaries of the city. Some of the key advantages of PFD are that they allow for the identification of main actors of WM and how they relate to each other. At the same time, they show the destination of different waste streams (Scheinberg et al., 2010b).

The PFD of a WMS, when combined with a mass balance, is transformed, in substance, into a Material Flow Analysis (MFA) (Allesch and Brunner, 2015; Brunner and Rechberger, 2017; Christensen, 2011a; Villeneuve et al., 2004). Even if they may be treated as synonyms (Masood et al., 2014), the application of MFA to WMS is a specific and growing scientific niche, with a scope that exceeds the general purpose of a PFD (see Allesch and Brunner, 2015 for a review). MFA can be focused on goods (e.g. mixed waste or a waste category) and/or on substances (e.g. phosphorous). Moreover, the MFA field is advanced in the treatment and calculation of important (but generally absent in PFD) aspects of WMS, like stocks and its variations, uncertainties of flows and stocks, or the standardization of diagrams using specialized software.

As in the case of the PFD, the construction of an MFA implies the acquisition of qualitative information related to actors and processes. However, due to its quantitative nature, it is a suitable base for the calculation of indicators related to the amount of waste entering or leaving a process or the system. Yet, their usefulness will depend on the quality and detail of available information.

In the case of recycling rates, information requirements are mainly related to (EPA, 1997; Ferronato and Torretta, 2019; Hotta et al., 2016; Wilson et al., 2009): a) the structure of the recycling system (formal and informal) b) the amount of waste generated; c) the waste composition; d) the quantity of waste diverted from final disposal. Importantly, the first point determines the level of detail in which the information should be available for the others. If different strategies are defined for different waste generation sources or group of them (i.e. a recycling campaign focused only on households), or at defined spatial sectors (i.e., the most populated sector or defined neighbourhoods), the information related to points b, c, and d should be available at these levels if a proper evaluation of these recycling strategies is desired (Hotta et al., 2016).

Moreover, in the Global South, where informal actors are often relevant to the performance of the recycling system (Ferronato et al., 2019; Wilson et al., 2006), incorporating the flows related to them is crucial. Also, this information is of vital importance to boost the inclusion of the informal recycling sector (IRS) itself in the formal WMS, an aspect that is considered essential to the achievement of circular economy in the Global South (Velis, 2017; Velis et al., 2012). However, measuring these flows can be challenging, because informal activities are -in most cases- part of the shadow economy (Schneider et al., 2010).

In the case of incorrect waste disposition, the challenge may be related to its illegality, to the identification of the source of waste (individuals, trucks, skips) and to the rapid change of the open dumping locations.

In Buenos Aires province, Argentina, where informal recycling and open dumping are part of the WMS of most cities to a greater or lesser extent, relatively recent legislation has compelled municipalities to divert waste from final disposal according to specific targeted-in-time percentages and to eradicate open dumps. However, due to limitations mentioned above, how to measure the achievement of these objectives is not well understood.

In this work, we combine MFA and information obtained through waste characterizations in a mass balance table to design, calculate and analyse recovery and performance indicators of formal and informal recovery strategies in place in Tandil, an intermediary city of Buenos Aires province.

Thus, the objectives of this study were: a) to apply the MFA approach to the WMS of Tandil city by incorporating measurement uncertainties; b) to use this information to conceptualize and calculate the indicators needed to evaluate the recovery potential and current performance of strategies in place (formal and informal); c) to explore, on the bases of obtained results, ways to improve the WMS functioning, regarding the local legislation and the drivers of the ISWM.

2. Materials and methods

2.1 Study area

Tandil city is located at the southeast of Buenos Aires province (see Figure 1). The last census' projections estimate, for 2019, a population of 137.922 for the county of Tandil, out of which approximately 94% lives in the head city and the rest in four surrounding towns. The predominant soil characteristics, very rich in nutrients, favour the development of dryland farming which, along with animal husbandry, are the main economic activities of the county (Falasca et al., 2002).

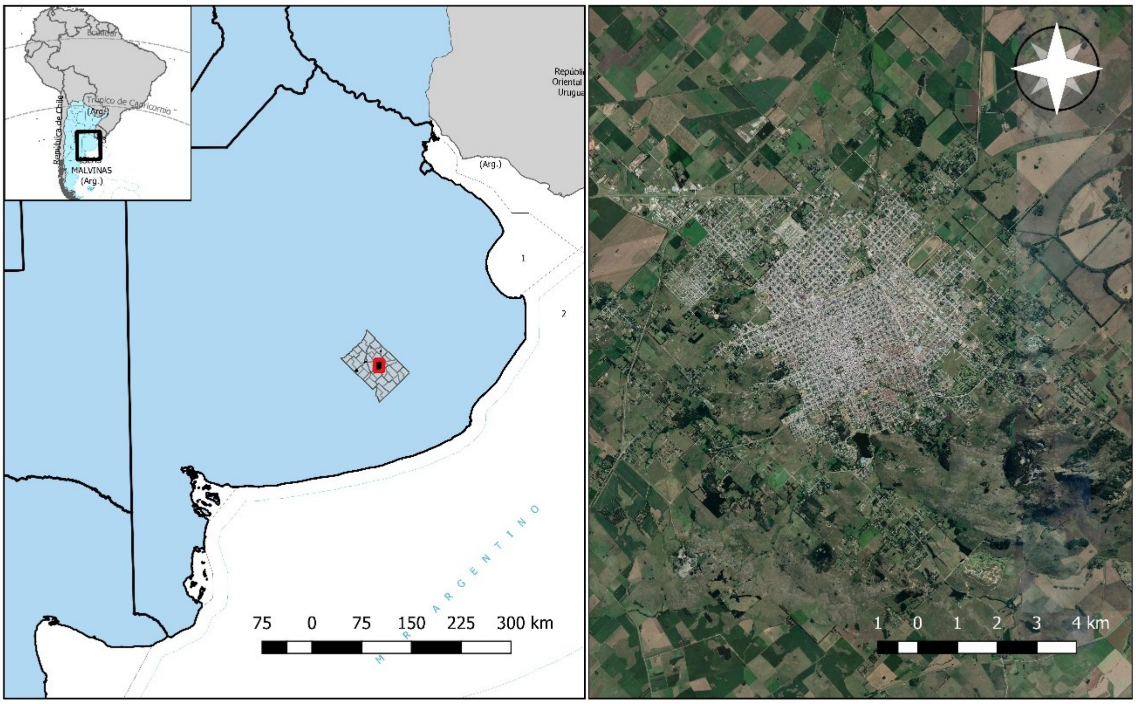


Figure 1. The county of Tandil (4,935 km2) in Buenos Aires province with Tandil city in red (left) and the city in detail, with its square blocks in urbanized areas, typical of Latin American cities (right).

2.2 Tandil waste management system

There are three main municipal solid waste (MSW) circuits in Tandil: 1) the core system of collection and final disposal of mixed waste, driven by the municipality; 2) the recovery of recyclable materials, historically conducted by waste pickers and, since a few years ago, also by non-profit organizations (NGOs, civil associations, etc.) with municipal support, and; 3) the private containers service circuit.

In the first, MSW is initially disposed in plastic bags at sidewalks, collected by compactor trucks and end-disposed in a sanitary landfill. Collection coverage rate is approximately 100%, decreasing occasionally if an offset occurs between the city growth and the planning of collection routes. People and enterprises can also bring waste directly to the landfill, but compared to the main collection system, this is negligible.

The second recovery-for-recycling circuit can be divided into a formal and an informal sub-circuits. In the formal sub-circuit, recycling waste is disposed by citizens in collection facilities under a bring system. These so-called "Clean Points" are managed by the municipality and receive, from households: plastics (PET and HPDE), paper, board, tetra brik containers, glass, metals, and Waste Electrical and Electronic Equipment (WEEE). WEEE is repaired and reused by the local university or sent for recycle/disposal out of Tandil, and glass is delivered for free to a local intermediary due to its low price. The remaining collected waste is assigned to a different non-profit organization, which depends on the category to which the collected waste belongs. Then, these organizations classify and commercialize the materials, either directly in Tandil or in Buenos Aires city, to which the materials are sent by train. In the informal sub-circuit, waste pickers collect, mainly exclusively from commerce, the materials they can sell directly in Tandil. These materials are paper, cardboard, and scrap metals.

Figure 2. a) A municipal Clean Point, where citizens can bring some types of recycling waste (left and centre) and the manual sorting and pressing in the *Taller Protegido* (right). b) Initial disposal in sidewalks (left), the municipal collection and transportation service (centre) and the sanitary landfill

(right). c) A waste picker self-made bike-pulled trolley for board collection in the city centre (left) and a motorized waste picker collecting board from a peripheral commercial axe (centre); at the right, an intermediary's shed. d) Private skips containing different kind of wastes (left and centre) and an open dump (right) where part of these skips is disposed (we see in the picture a skip-truck). Photo credits: the author, except for: b-centre (*La Voz de Tandil*) and c-right (Soledad Vidal), with permission.

Finally, we can identify the circuit of private skips. They are metal containers of different sizes that private users can hire and that are delivered and removed by special trucks. Although originally this service was intended to provide a mechanism to dispose Construction and Demolition (C&D) waste, the lack of a municipal collection service of voluminous waste has converted this circuit in a destination of all kind of waste. Furthermore, even if its destination is supposed to be the sanitary landfill, numerous open dumps have been detected where private companies empty their containers (see for example ABC Hoy, 2018 or; El Eco de Tandil, 2017).

2.3 Material Flow Analysis

As indicated by Brunner and Rechberger (2017), the construction of a MFA is a goal-oriented iterative process. It starts with a qualitative model and then, by means of improving of rough flows' estimations, leads to a quantitative model that should fulfil the objectives of the study.

Our investigation followed an iterative path, updating the goal of the application of MFA as new information was available. It started with a simple model, aimed at describing and understanding the WM system. This allowed us to identify key actors to be interviewed, key places to be visited, and available as well as lacking quantitative information. Then, we started a field work with the IRS of Tandil, and we planned and implemented the first household waste characterization of the city (Villalba et al., 2020). Importantly, our work was also influenced by disruptive information in the local press, such as complaints about illegal open dumps.

With this new information available, we could define new objectives for the MFA, according to the objectives of this study.

2.3.1 System construction

2.3.1.1 Spatial and time boundaries

The clear definition of the system boundaries is crucial (Allesch and Brunner, 2017). For the present study, we decided to focus on the year 2017 because the first waste composition information was available this year and official information is also available for this period. The spatial boundary was defined as the Tandil city.

We consider waste all the flows of material entering to the waste management system as defined in section 2.2. We therefore excluded flows related to the direct selling of discard materials from producers (e.g. paper residues from a printing house) to industry or intermediaries, where there was no intervention of external actors.

2.3.1.2 Processes

As recommended by Christensen (2011b), we included in the system processes related to collection and transport, treatment and landfilling, or open dumping of waste. Only the last two final disposal processes were considered to have a stock.

We considered collection and transportation processes: 1) the municipal service for mixed waste; 2) the private skips' service; 3) the IRS service; 4) the Clean Points.

In the treatment phase, we included the intermediaries and the non-profit organizations that classify and sell the main fractions of recycling waste destined to industries: paper and cardboard, and plastics. Recycling industries or industries that receive this type of waste are excluded from the system because their outputs are not considered waste any more; they are considered raw materials instead.

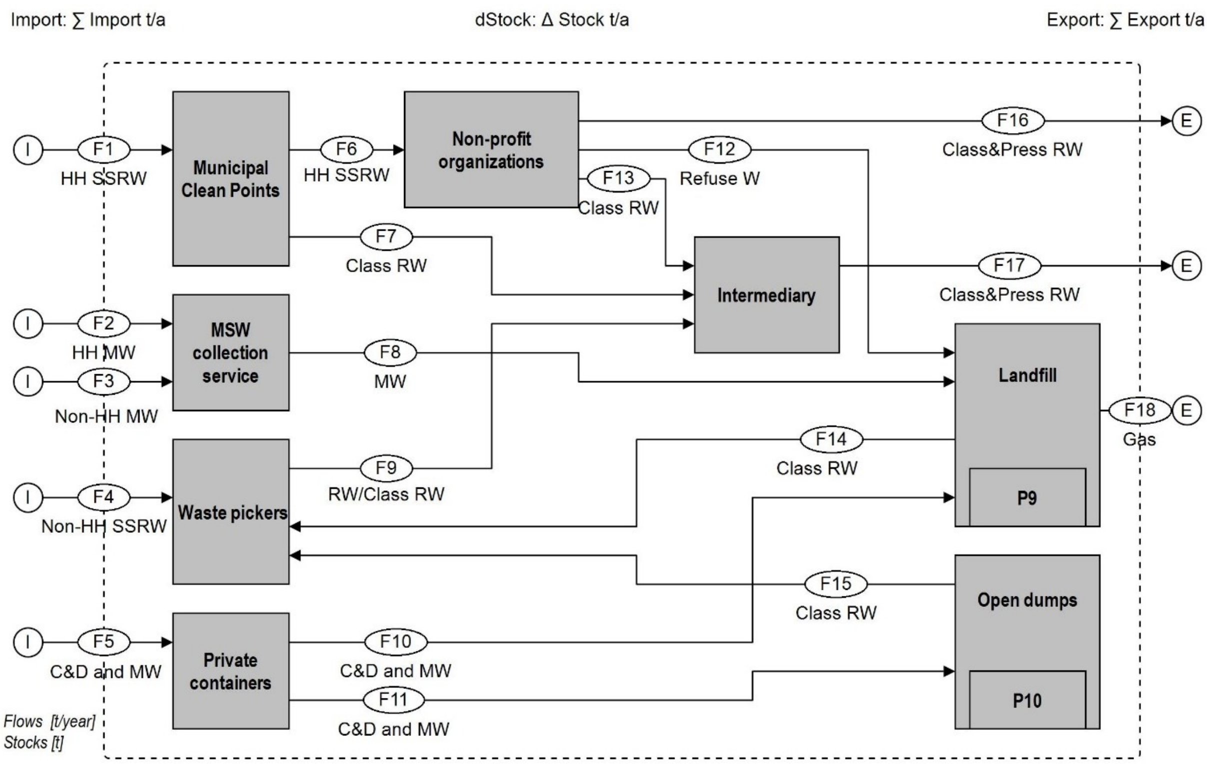
Finally, in the final disposal phase, we retained the sanitary landfill and a general process "open dumps" related to the incorrect disposal of skips' containers. We therefore dismissed micro open dumps formed occasionally due to incorrect disposal of individual sources.

2.3.1.3 Flows: categories of materials and units

In MFA, flows indicate how the analysed goods or substances enter or leave the system and how they circulate from one/more process(es) to another/others (Brunner and Rechberger, 2017). Their units are mass per time (e.g. ton/year) or mass per time and section (e.g. kg/pers/year). The later are called fluxes instead of flows. In the present work, we will analyse flows in tonnes per year (t/year).

Figure 3 shows a generic and simplified version of the WM system, constructed by using the STAN software (Cencic and Rechberger, 2008). This software allows for the calculation of the whole system if a minimum number of flows are valued, because it constructs the mathematical model associated to the "drawn" system and applies mass balance and error propagation (Brunner and Rechberger, 2017). Moreover, it supports the inclusion of different layers of goods or substances for the same system.

As different materials are processed to be recycled, we defined different categories of waste to be analysed, corresponding to the main recovered materials: paper, board, PET, HPDE, tetra brick, metals, and glass. We decided therefore to exclude from the analysis scrap metals recovered by waste pickers and WEE arriving to the Clean Points. Each studied material was assigned to a different layer in the STAN model.



RW=Recycling waste; Class RW= Classified recycling waste; Class&Press RW= Classified and pressed recycling waste; C&D= Construction and demolition waste; MW=Mixed waste

Figure 3. General system for Tandil constructed with the software STAN (goods layer). Subsequent layers with each waste category under study were created (see Supplementary Information).

2.3.2 Information sources strategy

On the basis of the MFA system defined, and considering the waste categories included in the study (layers of the STAN system), we defined, for each flow and stock, a strategy to obtain the quantitative information related to them. Table 1 presents the information sources, uncertainty estimations and complementary information of each flow and stock of the system.

Uncertainties associated to flows and stocks, in general, are not well addressed in waste management studies (Stanisavljevic and Brunner, 2014) and often neither in MFA publications (Rechberger et al., 2014). For our study, we aimed to assign a percentage of uncertainty to every flow and we supposed all uncertainties to be normally distributed.

In the cases in which we had two sources of information for the same flow, we kept the less uncertain, even when this implied calculating it through mass balance. This was the case for most flows leaving the municipal Clean Points, for which official information of recycling waste delivered to non-profit organizations demonstrated to be highly overestimated.

Table 1. Flows and stocks included in the MFA: ID, waste category, source information strategy, level of uncertainty and observations.

ID	Category/ies name/s	Information source/s	Uncertainty considerations	Observations
F1	General flow, Paper, Board, PET, HPDE, Tetra brick, Glass, Ferrous Metals	Mass balance	Calculated through error propagation by the software STAN	General flow is calculated as the addition of all flows' categories and Refuse waste from downstream classifying and/or pressing processes. Uncertainty derived from precision of professional balances used by non-profit organizations and a coverage factor
F2	General Flow, Paper, Board, PET, HPDE, Tetra brick, Glass, Ferrous Metals	Villalba et al. (2020)	Calculated following the recommendations of the SWA-tool for stratified data (European Commission, 2004) and an estimation of the total population of Tandil and its uncertainty	The population of Tandil was taken from the National Statistics and Census Institute previsions for the period 2010-2025 (INDEC, 2015b). An uncertainty of 3% has been associated to this estimation.
F3, F4, F5, F6	General Flow, Paper, Board, PET, HPDE, Tetra brick, Glass, Ferrous Metals	Mass balance	Calculated through error propagation by the software STAN	F5 have only the General flow, Paper and Board layers
F7	Glass	Official statistics published by the municipality (MdT, 2019)	15% estimated	Glass is the only category classified at the Clean Point and sent directly to the intermediary.
F8	General flow	Registers from the landfill managing organization	1% assigned to the balance	
	Paper, Board, PET, HPDE, Tetra brick, Glass, Ferrous Metals	From Capparelli (2019), which used a Standard Method to the characterization of mixed waste (ASTM, 2016)	10% estimated upon the percentage obtained by Capparelli (2019)	Example: from Capparelli (2019), paper is 2.44% of waste arriving to Landfill. Thus, we estimated the flow of paper to be 2.44 ± 0.24% of F8 - General flow. For the rest of materials, percentages are: Board, 3.72%; PET, 3%; HDPE. 1.76%; Tetra brick, 2%; Ferrous metals, 1.27%; Glass, 5%.

F9	General flow	Mass balance	Calculated through error propagation by the software STAN	
	Paper, Board	Information given by the intermediary and later validated through data triangulation	10% estimated	Intermediaries can be reluctant to give this information, either because they are evading tax payments or because they are aware of the possible organization of a waste picker's cooperative or similar, for which one of the main goals is to achieve a vertical integration in the value chain, i.e. bypassing middlemen. In our case, from a 2015 interview with the biggest intermediary of the city, we had an estimated value of recovered material by waste pickers that we later triangulated with sources from international literature (Linzner and Salhofer, 2014) and with results of a similar IRS census performed in Mendoza city (Argentina) in 2017 (Usach, 2019)
F10	General flow	Registers of skips from the landfill managing organization	1% assigned to the balance	
F11	General flow	Estimated on the basis of changes occurred in waste arriving to the landfill through skips when a big open dump was closed	15% estimated	We analysed how the closure of a big open dump on the first days of September 2017 (El Eco de Tandil, 2017) affected the quantity of waste arriving this way to the landfill. First, we checked the normality of available historical data (27 months before the closure) through a Shapiro-Wilks test. Then, we calculated its 99% confidence intervals (CI) and found that the quantity of waste disposed through skips the month of the closure tripled the upper limit of the CI.
F12	General flow	Mass balance	Calculated through error propagation by the software STAN	Addition of all flows' categories
	Paper, Board, Tetra brick, PET, HPDE, Ferrous Metals	Assumed to be 15% of waste sent from the Clean Points to non-profit organizations. Because reliable data is that registered in sales made by non-profit organizations	10% estimated	On the basis of interviews to the organizations and 3 full inspections of PET big-bags sent from the Clean Points to a non-profit organization where miss-classified waste reached in average 15% in weight

		(F13 or F16), this flow was calculated as 0.15*[kg sold]/0.85		
F13	General flow	Addition of categories' flows, based on sales registers	Calculated through error propagation	
	Board, Paper	Sales registers	1% assigned to the balance	Information provided by CIANE, the non-profit organization receiving paper and board from the Clean Points
	Ferrous Metals	Official statistics published by the municipality (MdT, 2019)	15% estimated	There is not a systematic weight of materials in the Clean Points
F14 and F15	General flow	Addition of categories' flows	Calculated through error propagation	
	Paper, Board	Assumed to be each flow 5% of what is recovered by waste pickers (F9)	10% estimated	
F16	General flow	Addition of categories' flows	Calculated through error propagation	
	PET, HDPE	Sales registers	1% assigned to the balance	Information provided by Taller Protegido, the non-profit organization receiving PET and HDPE from the Clean Points
	Tetra brick	Official statistics published by the municipality (MdT, 2019)	15% estimated	There is not a systematic weight of materials in the Clean Points
F17	General flow	Addition of categories' flows	Calculated through error propagation	
	Paper, Board, Glass, Ferrous Metals	Mass balance	Calculated through error propagation	
F18	General flow	LandGEM software	10% estimated	Based on historical registers of the landfill

3. Results and discussion

3.1 Definition of indicators

Based on the MFA system presented in Figure 3, we aimed at the design of indicators that could help to understand the functioning of the system regarding the objectives of the study. For this, we first conceived a mass balance table, inspired by the Standard Model of Water Loss of the International Water Association (IWA) (Alegre and IWA, 2000), which served to design the indicators described below. Figure 4 presents the mass balance table and how most of its related indicators are constructed.

3.1.1 Global recovery indicator

A general indicator of waste recovery can be defined on the basis of all waste inputs and all recovery flows (Eq. 1).

$$GRI = \frac{(F16+F17)}{(F1+F2+F3+F4)} * 100 \quad (1)$$

where GRI is in % and all flows are in t/year.

3.1.2 Formal and informal recovery indicators

To measure how the IRS and the formal recovery system are contributing to the global indicator defined above, we defined the following indicators (Eq. 2 and 3).

$$FRI = \frac{F7+F13+F16}{(F1+F2+F3+F4)} * 100 \quad (2)$$

$$IRI = \frac{F9}{(F1+F2+F3+F4)} * 100 \quad (3)$$

where all flows are in t/year and FRI and IRI are in %. By definition, the addition of both will equal the GRI (Eq. 1).

3.1.3 Maximum Recoverable Under Current Strategies (MRUCS) and Not Recoverable Under Current Strategies (NRUCS)

The global recovery indicator defined in section 2.4.1 is not well suited to evaluate (alone) the recycling performance in Tandil. This is because not all the waste arriving to the system can be recovered. Under the existing recovering strategies (formal and informal), only some materials are dealt with, that represent a fraction of the total input. However, we consider important to measure, first, what percentage of this total input is dealt with through the current targeted materials (see section 2.3.1) at each targeted source (households and other sources) and, second, what percentage is not dealt with (Eq. 4 and 5).

$$MRUCS = \frac{(\sum F1_{RWi}+\sum F2_{RWi}+\sum F3_{RWj}+\sum F4_{RWj})}{(F1+F2+F3+F4)} * 100 \qquad (4)$$

where each RW_i is a waste category flow targeted by the formal circuit (arriving from households) and each RW_j is a waste category flow targeted by the informal circuit.

Importantly, this indicator only considers capacity according to the targeted materials at each source, but does not consider infrastructure, logistics, costs, and other aspects related to a real recovery capacity. It is focused on the limits of current strategies in place. Therefore, what is considered recoverable refers to the current addressed materials.

Complementarily, we can define the Not Recoverable Under Current Strategies as:

$$NRUCS = 1 - MRUCS \qquad (5)$$

3.1.4 Effective Use (EU) of MRUCS

As we obtained the maximal potential of recovery under current strategies, it is possible to evaluate at which percentage the city is effectively using the MRUCS.

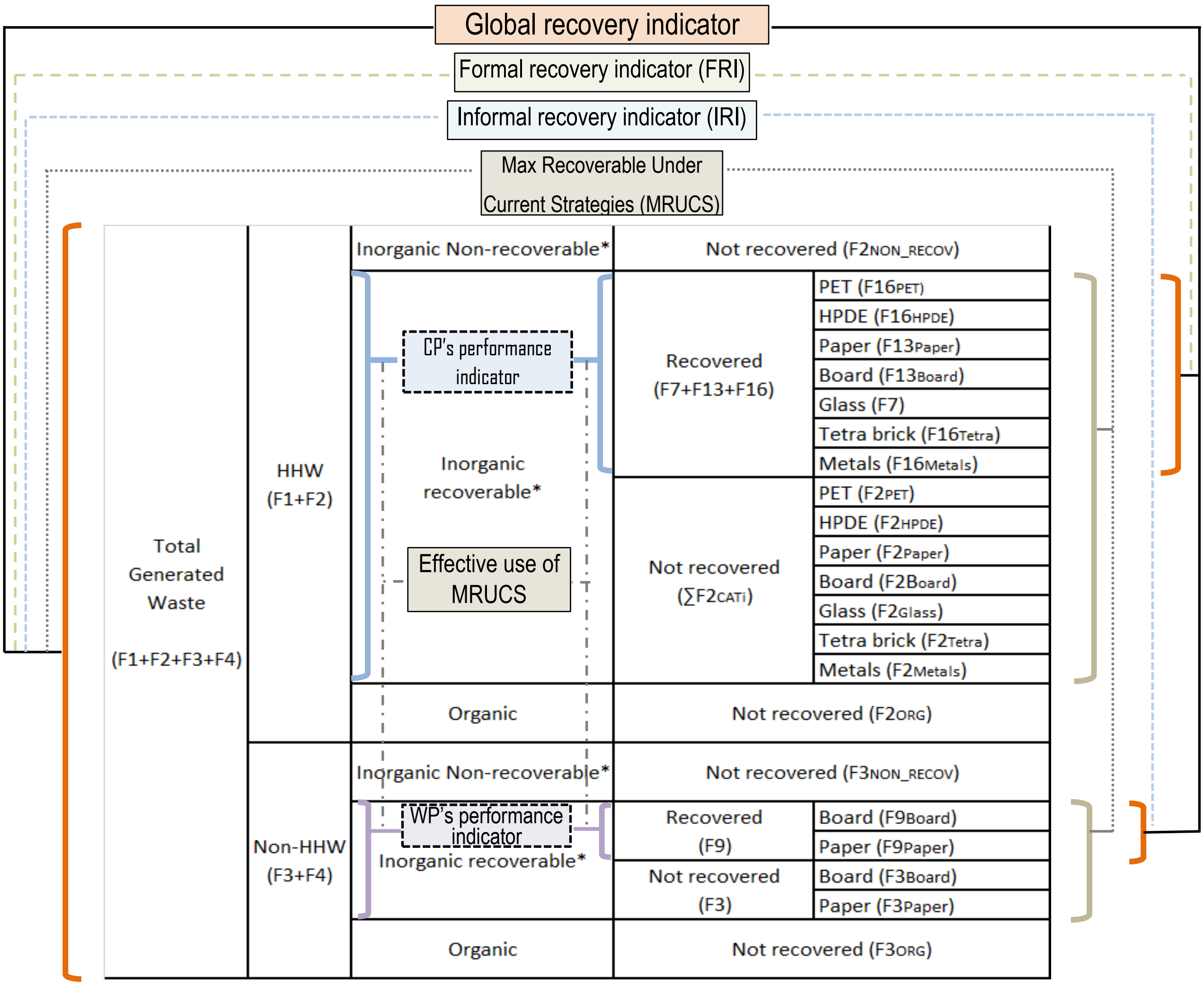
$$EU\ of\ MRUCS = \frac{(\sum F1_{RWi}+\sum F4_{RWj})}{(\sum F1_{RWi}+\sum F2_{RWi}+\sum F3_{RWj}+\sum F4_{RWj})} \qquad (6)$$

3.1.5 Clean Points and waste pickers strategies performance indicators

If we consider that the formal and informal circuits of material recovery are focused on distinct materials and sources, it is possible to measure the effectiveness of each strategy (Clean Points and Waste Pickers) as regards their targeted source of waste. For this, we defined the next two indicators (Eq. 7 and 8).

$$CP's\ performance = \frac{\sum F1_{RWi}}{(\sum F1_{RWi}+\sum F2_{RWi})} \qquad (7)$$

$$WP's\ performance = \frac{\sum F4_{RWi}}{(\sum F3_{RWi}+\sum F4_{RWi})} \qquad (8)$$



* It refers to the targeted materials under the current functioning of the system

Figure 4. System mass balance table for the current recovery strategies and all general indicators.

3.1.6 Individual materials indicators

Finally, having the adequate disaggregated information, it is also possible to calculate, for each material recovered in Tandil, its recovery percentage (Eq. 9).

$$Recovery\ of\ material\ i = \frac{F7_i + F13_i + F16_i + F9_i}{F1_i + F2_i + F3_i + F4_i} * 100 \qquad (9)$$

Complementarily, we analysed: 1) in which percentage the individual material is recovered from each generation source (Eq. 10 and 11); 2) in which percentage this recovery is performed by formal or informal actors (Eq. 12 and 13), and; 3) in which percentage each material is generated at households or at other sources (Eq. 14 and 15).

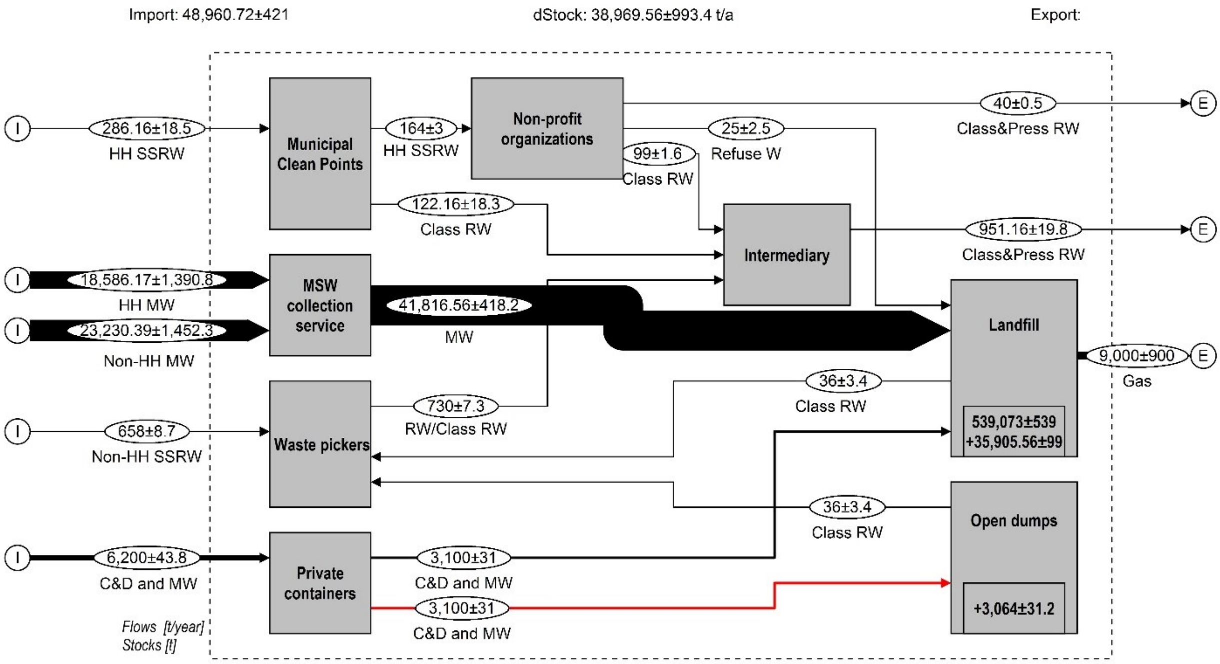
$$RecHH = \frac{F7_i + F13_i + F16_i}{F1_i + F2_i} * 100 \quad (10) \qquad RecNonHH = \frac{F9_i}{F3_i + F4_i} * 100 \quad (11)$$

$$Formal = \frac{F7_i + F13_i + F16_i}{F7_i + F13_i + F16_i + F9_i} * 100 \quad (12) \qquad Informal = \frac{F9_i}{F7_i + F13_i + F16_i + F9_i} * 100 \quad (13)$$

$$GenHH = \frac{F1_i + F2_i}{F1_i + F2_i + F3_i + F4_i} * 100 \quad (14) \qquad GenNonHH = \frac{F3_i + F4_i}{F1_i + F2_i + F3_i + F4_i} * 100 \quad (15)$$

3.2 MFA of general flows

Fig. 5 presents the results obtained from the WMS model by using the STAN software and values obtained from different layers. As the arrows' thickness is proportional to the value of the represented flow, it is easy to observe that the vast majority of waste entering the system is conducted to the sanitary landfill through the MSW collection service process.



RW=Recycling waste; Class RW= Classified recycling waste; Class&Press RW= Classified and pressed recycling waste; C&D= Construction and demolition waste; MW=Mixed waste

Figure 5. Results of general flows of the system, presented with STAN. In red, waste disposed incorrectly.

3.3 Indicators' results

Tables 2 and 3 present the results of all calculated indicators. We could calculate the associated error of each indicator by means of error propagation rules (Taylor, 1997), which was possible because we could account for flows' uncertainties (Table 1).

As it could be attended on the basis of the general picture obtained through the MFA, the Global Recovery Indicator (GRI) is very low. This is in part related to the recovery potential of the current strategies in place (measured through the MRUCS, not considering infrastructure), which, in the best case, could recover approximately 20% of the total waste entering the system (from households, less than 9%). Considering the GRI, this means that the effectiveness of the current strategies in place is slightly above 10%.

Waste pickers are responsible of more than 70% of the recovered waste in Tandil, according to the system borders' definition. Importantly, this percentage does not account for scrap recovery, which is out of the scope of this study, but on which waste pickers also focus their attention and are highly active. However, our result is consistent with other studies focused on cities from developing countries. Bidegain (2011) signals that 65% of recycled materials in Montevideo is collected by the informal recycling sector, while Scheinberg (2012), analysing more than 10 cities from developing countries, found values above 80% in most cases.

Table 2. Results of the general indicators defined in section 2.4

General indicators	Value [%]
Global Recovery Indicator (GRI)	2.3 ± 0.16
Formal recovery indicator (FRI)	0.6 ± 0.07
Informal recovery indicator (IRI)	1.7 ± 0.1
Maximum Recoverable Under Current Strategies (MRUCS)	20.9 ± 2.1
Not Recoverable Under Current Strategies (1 - MRUCS)	79.1 ± 2.1
Effective use of MRUCS	11.1 ± 1.3
Clean Points' performance indicator	7.0 ± 1.0
Waste Pickers' performance indicator	40.0 ± 8.0

At the same time, when comparing formal and informal strategies performances, i.e. their effectiveness in recovering the materials their target from the source they target, we found that waste pickers are reaching 40% of this indicator, while Clean Points are only reaching 7%. This difference may be due to several reasons: on the one hand, to the experience in material recovering for subsistence accumulated during decades by waste pickers, which made them focus on medium or large generators, with whom they have a personal contact and implicit agreements; on the other hand, the existence of only two municipal Clean Points for the whole city means that, for most households, even if they are willing to recycle, taking materials to one of these two points represents a considerable effort. Table 3 shows the results of indicators related to each recovered material.

Table 3. Results (in %) of indicators defined for each recovered material.

		Recovery by source		Recovery by strategy		Generation by source	
Material	Recovered	HH	Non-HH	Formal	Informal	HH	Non-HH
Paper	21.2 ± 4.2	7.6	50.2	24.4	75.6	70.9	29.1
Board	26.0 ± 4.9	4.5	35.1	5.1	94.9	30.0	70.0
PET	2.9 ± 0.4	9.6	-	100	-	30.8	69.2
HDPE	0.2 ± 0.02	1.2	-	100	-	15.9	84.1
Glass	5.5 ± 1.4	9.0	-	100	-	60.9	39.1
Tetra brik	0.1 ± 0.02	0.4	-	100	-	21.9	78.1
Ferrous Metals	0.8 ± 0.2	2.5	-	100	-	31.8	68.2

Regarding the general recovery performance, paper and board are the best positioned. This is mainly due to the work of waste pickers, which are responsible of a large part of the recovery in both cases, especially in the case of board.

Regarding the functioning of the Clean Points, we see that their performance is higher in the cases of glass and PET, in which they recover almost 10% of what is produced as waste in households. This is not equally reflected in the general recovery indicator of each material because they are generated differently by source: glass is predominantly generated in households, while PET is generated in other sources.

HDPE, in comparison with PET, and even if they are both usually labelled and promoted for recycling under the general denomination of “plastics”, has a very low recovery rate. This difference may be due to the “popularity” of PET bottles as recycling waste and to a possible lack of information about the recoverability of HPDE containers by citizens. Further qualitative research would be needed to better understand this aspect.

In the case of Tetra brik and Metals, the performance of the Clean Points is even lower. With the former, this may be due, in part, to the fact that, before 2017, this material was not accepted in the municipal facilities. In the case of ferrous metals (mainly cans), this may be related to the effort needed to clean the cans to avoid bad smells. In both cases, advanced qualitative research is needed to support or reject these assumptions and to find new responses.

When analysing in which source these waste streams are generated, we found that there are clear differences between them. While board is mainly generated in sources other than households, paper waste is mainly generated in households. We think this may be related to the high price of paper, which makes its recovery part of the business of large generators, therefore avoiding the waste management system as we defined it in our MFA system borders.

Most of the other waste streams, except for glass, are mainly generated in sources other than households. This raises concern about the municipal strategy, which is focused on the recovery from households of waste materials mainly generated elsewhere. The high recovery rate of glass, a category mainly generated in households, is rather an exception and may be related to the use of information provided by the municipality, which demonstrated to be highly overestimated in the case of paper, board, and PET.

3.4 Decision-making implications and policy recommendations

The assessment methodology we developed in previous sections is applicable to any city for which data is available or can be estimated. The obtained results open the way to exploring how the WMS and current strategies in place respond or could better respond in the future first, to local legislation, and second, to safe disposal and resource recovery practices associated to the integrated sustainable waste management framework (UNEP and ISWA, 2015; Wilson et al., 2015).

3.4.1 Province legislation

In Buenos Aires province, the 2010 Law 13592 of Integrated Solid Waste Management sets two main priorities for municipalities: 1) A total decrease of 30% of the waste sent to final disposal in 5 years since the approval of the ISWM local Plan; 2) the eradication of open dumps.

In relation to the first point, from the analysis of our indicators we can point out two principal observations. First, the importance of considering the performance of informal recovery actors, which is absent in the recovery indicators informed by the municipality (MdT, 2019). Ignoring their work means that the reported recovery in the city is much smaller. Second, the fact that the formal circuit supported by the municipality since 2015 (the targeted materials from the targeted source) can recover, in the best case, less than 9% of the waste arriving to the landfill. Moreover, considering the performance of the Clean Points' strategy in the year of study reported in Table 2, it is estimated that almost 30 new Clean Point facilities should be opened to obtain a result that would be far from the reduction objective of Law 13592. Obviously, achieving a 100% effectiveness is almost impossible, and complementary qualitative research is needed to understand the will of the citizens in participating of these changes.

With respect to the second priority, when we estimated the flow associated to skips disposed in open dumps, we took a conservative 50/50 proportion of correct/incorrect disposal. However, as explained in Table 1, the increase of waste arriving through skips at the landfill was three times the superior limit of the 99% confidence interval of previous disposal registers. Therefore, it is possible that up to 17% of the total waste final-disposed is done incorrectly.

Despite these observations, it is important to signal that Tandil is one of the few cities of the province having a sanitary landfill (OPDS, 2019). As in many developing countries, especially from the Latin American and the Caribbean region (Brunner and Fellner, 2007; Diaz, 2017), the priority in the province is still the safe disposal of not valuable solid waste. This explains why the city is often regarded as an example of waste management by foreign and local authorities. At the same time, it arises questionings about the adequacy of the Law objectives formulation regarding the reduction of waste sent to disposal, which was too ambitious and too difficult to measure.

3.4.2 Safe disposal and after-care free landfill

Regarding open dumps, while some authors suggest a punishment approach to resolve this problem (Seror and Portnov, 2020), we believe that, for our study case, an analogic or digital tracking system for skips would resolve illegal dumping in a relatively easy way.

However, even if all the waste were disposed in the landfill, the absence of a properly waste separation-at-source strategy would make it impossible to get an after-care free waste landfill, which is considered an additional goal of integrated waste management (Allesch and Brunner, 2014).

The case of batteries in Tandil is illustrative. According to official statistics (MdT, 2019), 7 tons of discarded batteries were collected in 2017 through a special separation program. However, an average consumption of batteries of more than 1 kg/pers/year has been estimated for Argentina (Brailovsky, 2016). This means that, even if local statistics are correct, 95% of batteries of Tandil are either sent to final disposal (landfill or open dump) or are being stocked and will be discarded in the future. What is more, while the landfill was opened in 1998, the current program to divert batteries from the waste stream started in 2013.

This situation is worsened by the fact that the landfill collected leachate is sent to a treatment facility that does not work properly. From 10 years to now, the only function of the plant is to give a partial anaerobic and aerobic treatment to the leachate before its aspersion over the closed landfill modules (Landfill Responsible, personal communication). This reinforce the need of source separation.

Considering that the landfill in use is at the end of its life-cycle (less than 1 year to its closure), increased effectiveness in the divert of special waste from landfilled waste is imperative before the opening of a new one.

3.4.3 Resource recovery

Regarding the limits and performances of the strategies in place, several recommendations for improvement can be suggested, starting with the improvement of official statistics, which have demonstrated to be largely overestimated.

One of the most evident possible improvements is related to the valorisation of organic waste fraction, which represents more than half the waste generated at households (Villalba et al. 2020) and almost half the waste arriving to landfills in Argentina (ARS, 2012; Capparelli, 2019; The World Bank, 2015). Beyond the importance of reducing impacts and costs of landfilling waste, a composting strategy, for example, could allow for the recovery of a significant amount of nutrients available in biowaste (Zabaleta and Rodic, 2015).

Importantly, until recently, a resolution of the Sanitary and Agri-food Quality National Service (SENASA) prohibited the commercialization of compost produced from urban solid waste. However, a 2019 joint resolution by SENASA and the Environmental Control and Monitoring Office set a regulatory framework of compost production from urban waste. Additional incentives may be necessary, though. Scheinberg (2012) and Scheinberg, Wilson and Rodic (2010) signal that for Mali, where more than 80% of this stream is recovered, it is the dry sahelian climate which motivates the agricultural value chain to "pull" the demand of compost. In Tandil, this demand is absent because the city is located in one of the most soil nutrient-rich regions of Argentina.

Regarding inorganic waste, promoting and boosting the IRS work has shown to be an adequate strategy in developing countries (Velis et al., 2012) and is a key part of the ISWM framework (Wilson et al., 2015). The already high recovery performance of waste pickers in recovering board and paper from shops found through our analysis, however, raises concern about how much the IRS can improve it. The inclusion of new material categories to be recovered from shops, especially those not mainly generated in households, may be needed.

Moreover, a deeper analysis of available strategies for those inorganic waste categories that are not addressed today is needed. In the case of households, sanitary household waste (SHHW) and plastics other than PET and PEAD account for 18% of the total generated waste (Villalba et al. 2020). While in the first case reducing its generation may be difficult, the last is clearly related to packaging and may be reduced through a minimization strategy focused on this aspect. Importantly, this should be mainly addressed at a national and international level.

In the case of C&D waste managed through skips, it is possible to recover this fraction for reuse and, at the same time, it made little sense to use the scarce landfill capacity for it. A treatment step for this waste circuit may be adequate.

Overall, the challenge in the improvement of resource recovery will be to significantly increase the quantity of recovered materials while conserving an adequate quality (Stanisavljevic and Brunner, 2019).

4. Conclusion

Material flow analysis can provide a sound base for the development of indicators evaluating how a city performs regarding resource recovery and safe disposal, major components of ISWM.

Since recycling programs are generally focused on specific materials, waste composition data is crucial to estimate their recycling rates. When, in addition, recycling programs focus on specific waste sources (e.g., households), availability of waste composition data disaggregated at an adequate level is needed to properly assess the performance and find improvement paths of strategies in place. In developing countries, where waste pickers are often the main actor of resource recovery, estimating their contribution to final disposal reduction is imperative.

The general procedure followed in this article, along with the mass balance table and their related indicators, constitute an adaptable-to-case tool that can be used in other cities to analyse and find improvement opportunities for their waste management system.

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Supplementary Materials

S1. Information sources strategy

In Figure 3 of the original publication (reproduced below), we shown the general MFA scheme constructed on the basis of our qualitative research, which allowed us to identify flows to measure/estimate, process to assess, and actors to contact.

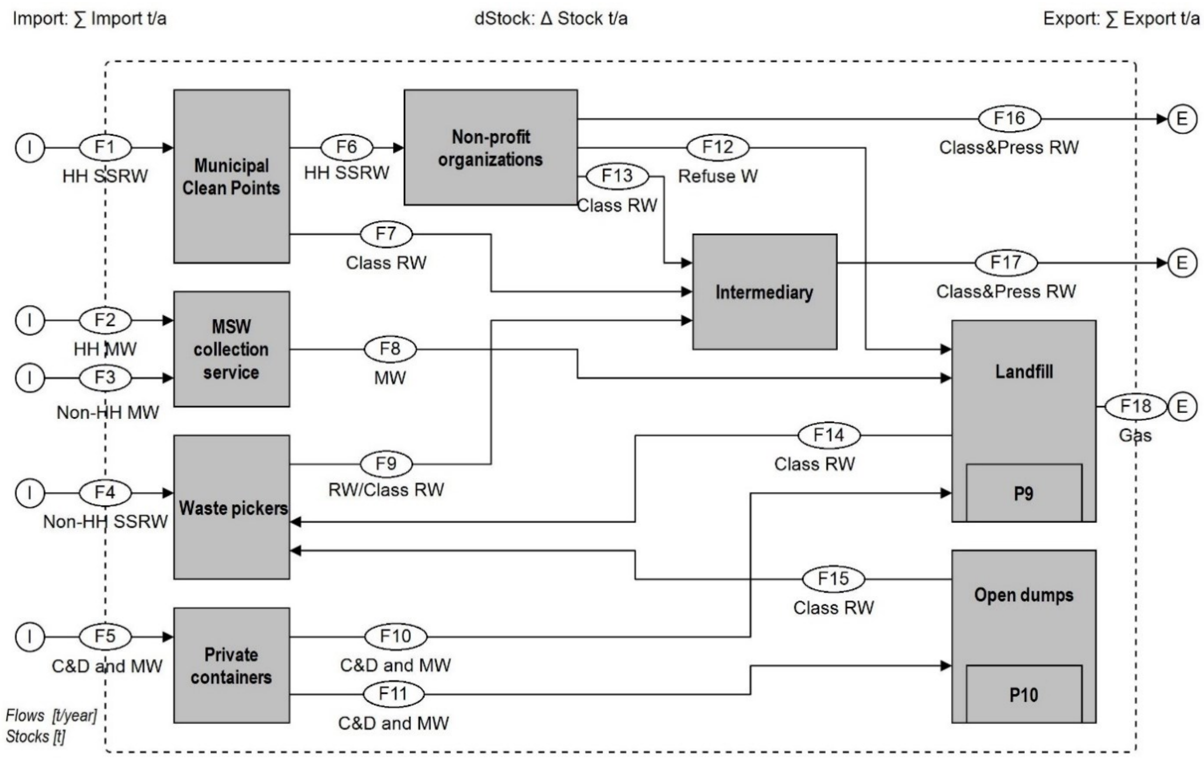


Figure S1: Reproduction of Illustration 3 of the original publication

Each flow, except off-gas from the landfill (F18), has a general value associated to the overall amount of waste it represents, and one or several specific values associated to the different waste categories studied in this work.

Therefore, we defined a strategy for each of these flows (general and specific categories). In the case of stocks, we only made an estimate of landfilled waste, using the Landfill Gas Emissions Model (LandGEM) from EPA (2005)[70].

[70] Available at https://www3.epa.gov/ttn/catc/dir1/landgem-v302.xls (accessed 26.11.2019)

When information sources were not fully reliable, or when the mass balance of a process was inconsistent, we did data triangulations and further analysis to validate the flows' values.

This occurred with the city official statistics related to recovered materials. The case of the PET and HPDE flows, processed at the Taller protegido -i.e., a non-profit organization aiming at the inclusion of disabled people-, was determinant in this regard. Sales records accounted for 38.1 t of PET and 1.5 t of HPDE recovered in 2017, while official statistics indicate 82.83 t of PET and HPDE recovered at the Clean Point for the same year. Since there were no alternative destination for plastic in 2017, mass imbalance was extremely high. Considering that no stock is formed in this process, even if a refuse flow existed, the inconsistence of the main flows was evident. A similar difference existed between paper and board official recovery statistics and sales registers.

During a field visit to Taller Protegido, we interviewed the person in charge of the process and performed a simple time study. It showed that, on average, they processed (classified and pressed) one bundle of 20-25 kg per hour of work. Therefore, working 7 hours per day and 5 days per week, their 100% production capacity was 45,5 t/year. This demonstrated that official statistics turned out to be misleading. Moreover, when asked about the origin of this information, the Clean Point responsible stated that they had made rough estimations based on the quantity of big-bags sent to each non-profit organization.

S1.1 Calculation of landfill stock using LandGEM 3.02

Tandil's landfill was opened in 1998, expanded in 2014 and is currently arriving to its end of life (see Figure S.2).

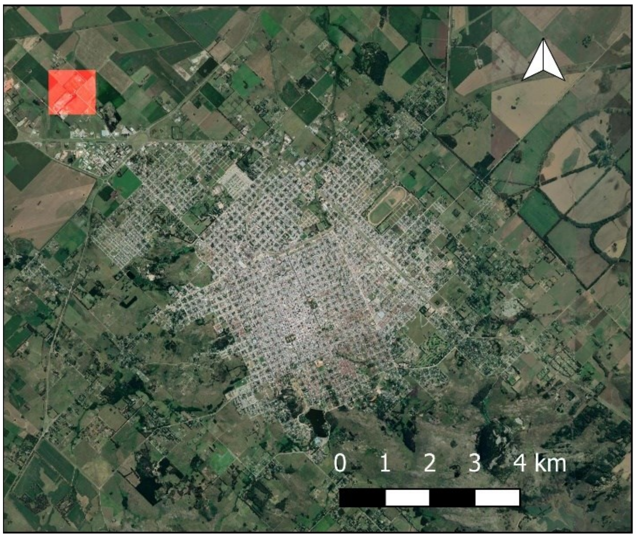


Figure S2. Location of the sanitary landfill (left). At the right: 1) the old open dump; 2) the first landfill (1998-2013); 3) the new sector (2104-2021?); 4) the leachate plant. Image source: Google Maps.

LandGEM 3.02 allows to obtain a model of emissions from the Landfill based on empirical data from United States landfills. Input information is the quantity of tons landfilled each year, from the opening of the landfill.

In our work, this information was provided by the landfill manager. To obtain the final stock for the year 2017 (P9 in Figure S1), we subtracted gas emissions of the period 1998-2016 to the disposed tons in the same period. F18 is therefore the gas emission result provided by the LandGEM for the year 2017.

Importantly, even if it is considered a matter of concern, water balance has not been addressed. Taking for granted the absence of liquid effluent emission declared by the landfill manager, we supposed that evaporation equal rainfall inputs.

S1.2 Flows from households (F2 and subcategories)

To obtain the overall flow of waste arriving from households and the quantity of waste of each category we used the data obtained by Villalba et al. (2020). The 95% confidence interval for each waste category was obtained using Equations 1 and 2, according to the SWA tool (European Commission, 2004).

$$s_{\hat{\bar{X}}} = \sqrt{\sum_{h=1}^{L} \left(\frac{N_h}{N} \right)^2 \frac{s_h^2}{n_h}} \qquad \left(for \frac{n_h}{N_h} \langle 0{,}05 \right) \tag{1}$$

where $S_{\bar{x}}$ is the overall standard deviation, Nh/N is the proportion of strata h, s_h is the standard deviation of the strata h and n_h is the number of samples available for the strata.

$$C.I. = \bar{x} \pm 1.96\ s_{\hat{\bar{x}}} \qquad (2)$$

where $\bar{x}$ is the mean value and $S_{\bar{x}}$ is the overall standard deviation.

Because the results of the waste characterization are in kg/pers/day, to obtain the final quantity of tons of waste generated in households (overall flow and flows of each waste category) in the year of study, we had to estimate the total population of Tandil for this year.

Thus, we took the population previsions of the National Statistics and Census Institute (INDEC) previsions for the period 2010-2025 (INDEC, 2015) for 2017 and we associated it an uncertainty of 3%. This value is based on the error occurred in the previous prevision (INDEC, 2008) -based in 2001's census- for 2010 with respect to the real data of 2010 obtained in the last census.

As the INDEC's prevision is made for the whole Tandil county (INDEC, 2015), we estimated the percentage of the county's population living in Tandil city in 2010 (year of the last census) and we supposed it to be the same for 2017.

Therefore, for each flow, we took the mean generation value in kg/pers/day and we calculated its associated 95% confidence interval with Eq. 1 and 2. Then, we multiplied the mean value by the estimated population of Tandil for year 2017 (12699 inhabitants) and applied error propagation rules (Taylor, 1997) to calculate the final uncertainty of the total waste flow.

S1.3 Calculation of waste illegally disposed trough skips

In section 2.3.2 of the original publication, we briefly explained how we estimated the flow of illegally disposed skips in open dumps. Here we give more details.

The 4th September 2017 in social networks and the 5th September in printed and digital media (El Eco de Tandil, 2017), a big open dump was publicly denounced in Tandil. Some weeks later, when interviewing the manager of the landfill, we asked him about the quantity of tons arriving to the landfill through skips. He mentioned that a significant increase recently occurred because of the closing of a big open dump. Also, he said that it was probable that a new illegal disposal site will soon be found.

We therefore decided to analyse how disposed tons through skips had changed the month of the closure. Figure S3 presents the evolution of disposed tons through skips according to landfill registers. Figure S4 shows, in a density graph, the distributions of monthly disposed tons through skips in the sanitary landfill. The blue distribution corresponds to monthly disposed tons previous to the closing of the open dump. The blue dot shows the mean value associated to it. The red dot shows the quantity of tons disposed the month in which the open dump was closed (September 2017). The green distribution corresponds to monthly disposed tons after the closing month.

We can see how the mean value is higher after closure of the open dump.

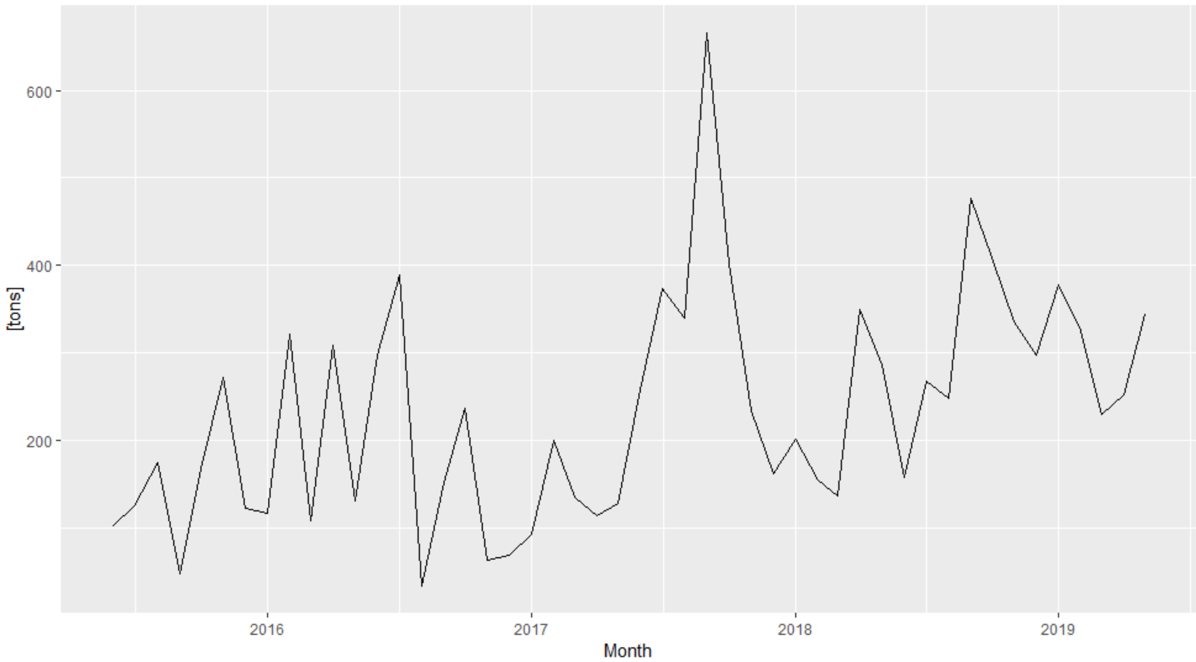


Figure S3. Tons disposed in the sanitary landfill through skips. The pic corresponds to September 2017.

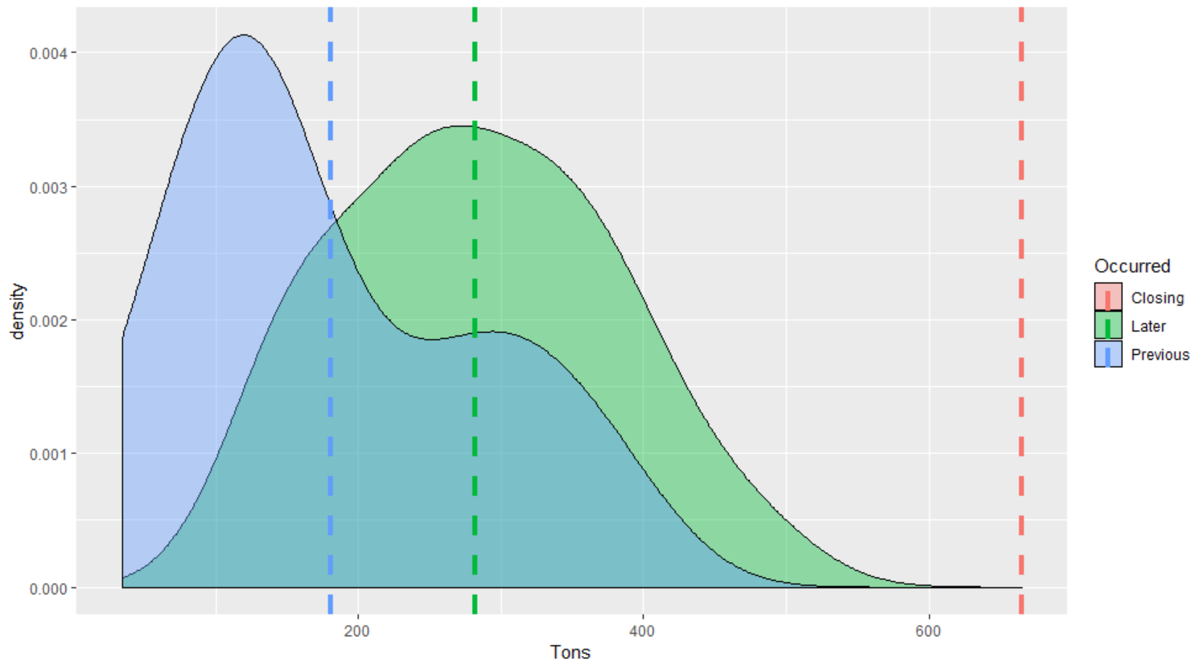


Figure S4. Distributions of tons arriving at the landfill through skips and mean values (blue: before the closure; green: after the closure). The red dot indicates the quantity of tons disposed the month of the closure of the open dump.

Also, we decided to perform a Shapiro-Wilks normality test to data corresponding to tons disposed the months previous to the closure. As the result was positive, we calculated the 99% confidence interval with a statistic software. The Inferior Limit was 139.63 tons and the Superior Limit 221.90 tons. Table S1 shows the raw data of this calculations.

However, we finally assumed the illegal flow to be equal to the legal one.

Table S1. Raw data of the number of tons disposed at the landfill through private skips. Source: USICOM S.A.

Before		Closure		After	
Month	Tons	Month	Tons	Month	Tons
June 2015	102.28	September 2017	665.43	October 2017	402.32
July 2015	124.91			November 2017	233.73
August 2015	175.17			December 2017	161.67
September 2015	47.82			January 2018	201.4
October 2015	167.76			February 2018	154.95
November 2015	271.66			March 2018	137
December 2015	122.4			April 2018	350.29
January 2016	117.28			May 2018	286.11
February 2016	321.31			June 2018	157.05
March 2016	108.69			July 2018	267.23
April 2016	309.19			August 2018	247.96
May 2016	130.84			September 2018	476.21

June 2016	297.56		October 2018	409.09
July 2016	388.62		November 2018	335.55
August 2016	34.07		December 2018	297.33
September 2016	151.88		January 2019	377.67
October 2016	236.38		February 2019	325.03
November 2016	62.89		March 2019	229.32
December 2016	68.1		April 2019	252.91
January 2017	92.92		May 2019	344.18
February 2017	200.27			
March 2017	135.73			
April 2017	114.27			
May 2017	128.46			
June 2017	257.32			
July 2017	373.07			
August 2017	339.88			

S2. Results

S2.1 Calculated flows

Table S3 presents the results of the calculated flows (see also Table S1 and section S1 for used methodologies).

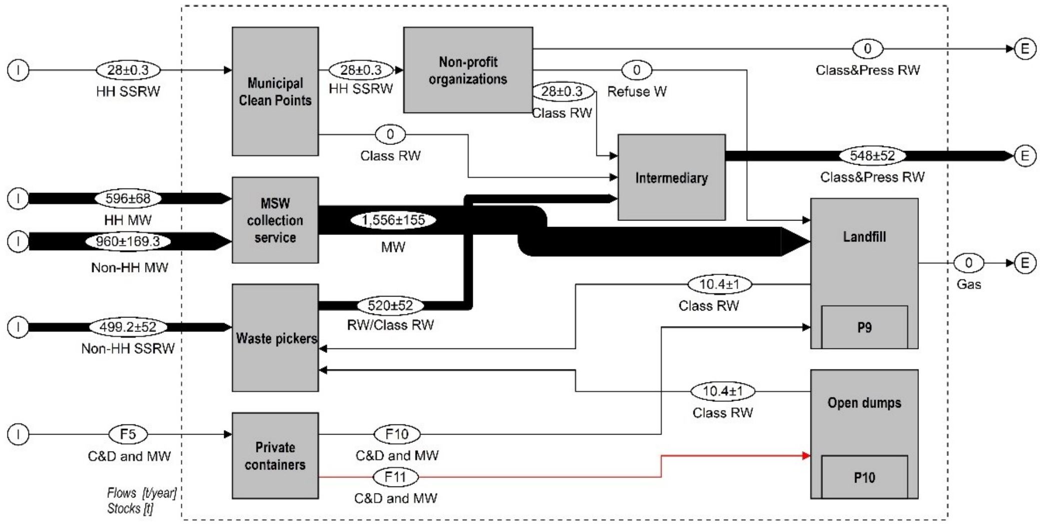
Table S2. Overall and category specific calculated flows (in tons).

	General flow		Paper		Board		PET		HDPE		Tetra brick		Metals		Glass	
Flow ID	Value	Uncertainty	Value	Uncertainty	Value	Uncertainty	Value	Uncertainty	Value	Uncertainty	Value	Uncertainty	Value	Uncertainty	Value	Uncertainty
F1	286.16	18.5	67	0.7	28	0.3	38.1	0.4	1.45	0.01	0.8	0.1	4.3	0.6	122.18	18
F2	18586.17	1390.84	813.7	88.2	596	68	359.6	38.7	115.8	22.6	182.8	24	166	28	1226	240
F3	23230.19	1452.31	206.3	134.8	960	169.3	894.4	130.9	620.2	77.4	653.2	87.4	365	59.9	864	318.9
F4	658	8.74	156	21.3	499.2	52	0	-	0	-	0	-	0	-	0	-
F5	6200	620.8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
F6	164	3	67	0.7	28	0.3	38.1	0.4	1.45	0.01	0.8	0.1	4.3	0.6	0	-
F7	122.16	18.3	0	-	0	-	0	-	0	-	0	-	0	-	122	18
F8	41816.56	418.2	1020	102	1556	155	1254	125	736	74	836	64	531	53	2090	210
F9	730	7.3	208	21	520	52	0	-	0	-	0	-	0	-	0	-
F10	3100	31	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
F11	3100	620	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
F12	25	2.5	0	-	0	-	0	-	0	-	0	-	0	-	0	-
F13	99	1.6	67	0.7	28	0.3	0	-	0	-	0	-	4.3	0.6	0	-
F14	36	3.4	26	2.6	10.4	1	0	-	0	-	0	-	0	-	0	-
F15	36	3.4	26	2.6	10.4	1	0	-	0	-	0	-	0	-	0	-
F16	40	0.5	0	-	0	-	38.1	0.4	1.45	0.01	0.8	0.1	0	-	0	-
F17	951.16	19.8	275	21	548	52	0	-	0	-	0	-	4.3	0.6	122.18	18
F18	9000	900	-	-	-	-	-	-	-	-	-	-	-	-	-	-

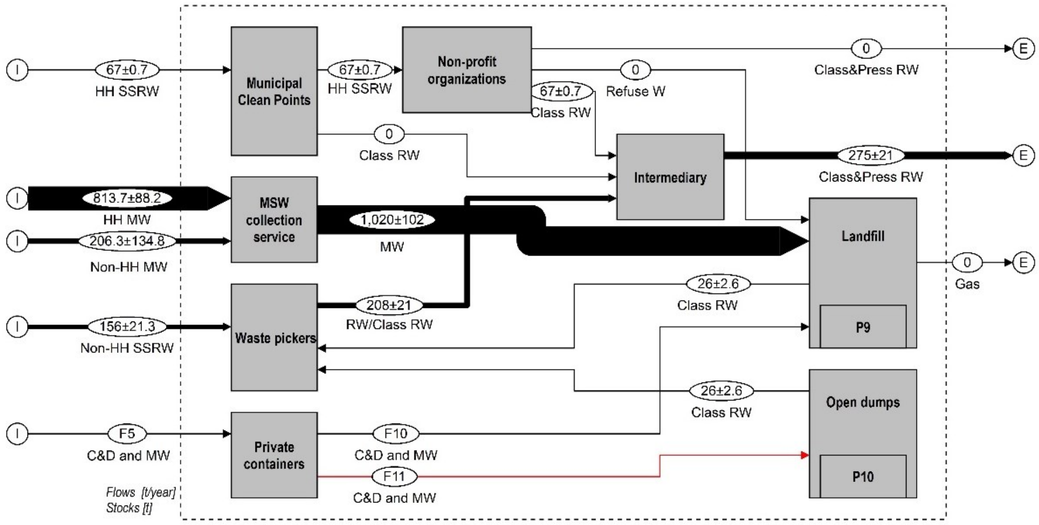
ND=Not determinated; “-“= Not corresponding

S2.2 MFA of recovered materials (layers of the STAN software file)

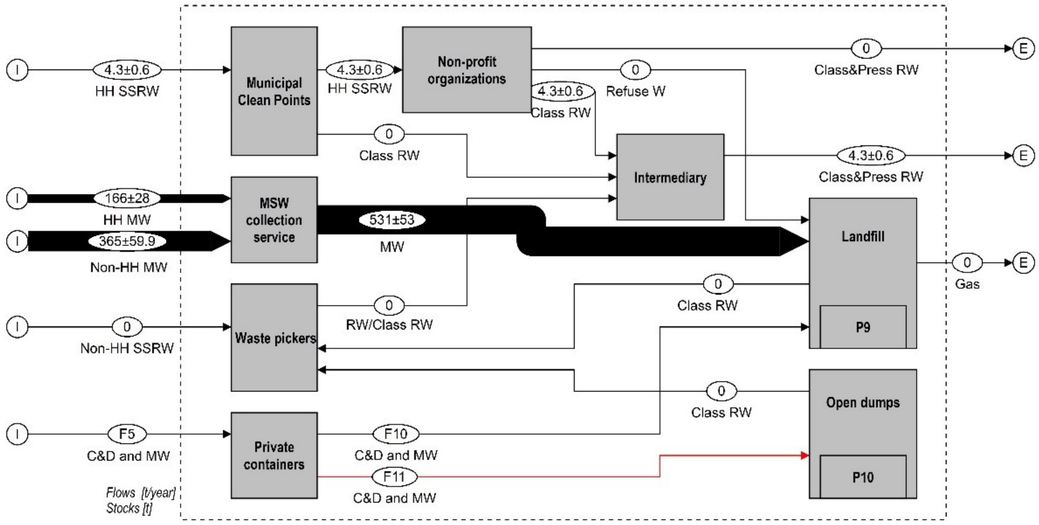
S2.2.1 Board



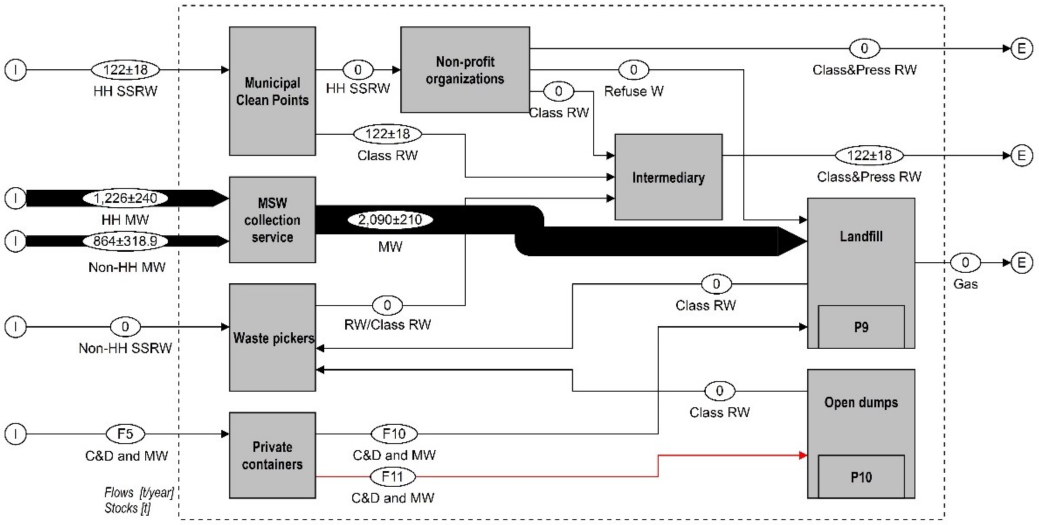
S2.2.2 Paper



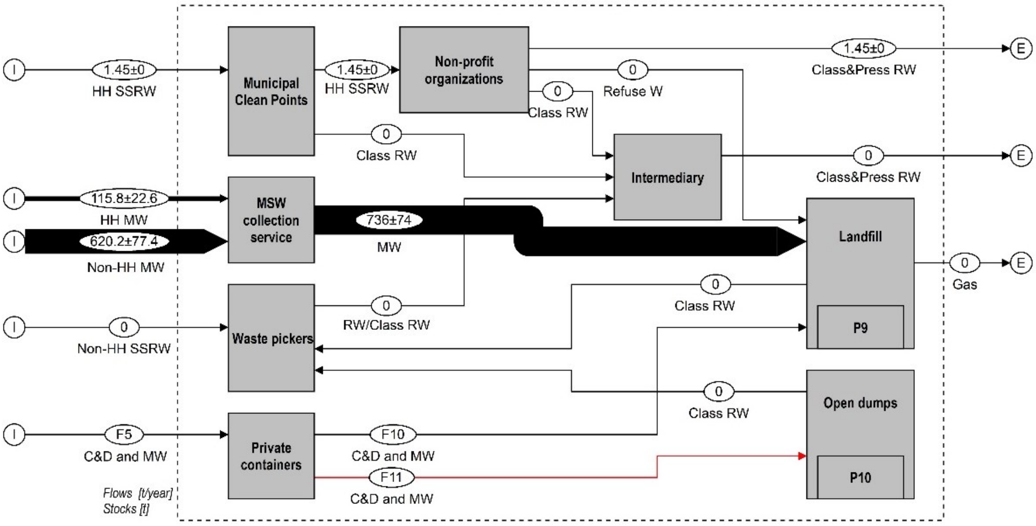
S2.2.3 Ferrous Metals



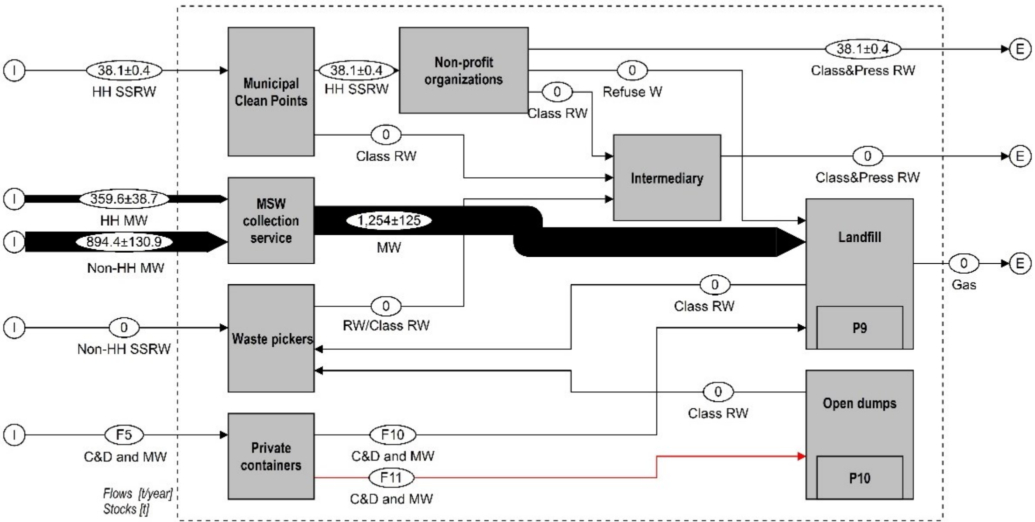
S2.2.4 Glass



S2.2.5 HPDE



S2.2.6 PET



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Article 3: Recent evolution of the Informal Recycling Sector (IRS) in Argentina within the "popular economy": measuring its impact through a case study in Tandil (Buenos Aires)

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Abstract

The integration of the informal recycling sector (IRS) into formal waste management (WM) systems is imperative to the implementation of the circular economy in the Global South. In Argentina, after the 2001's crisis, some big cities like Buenos Aires improved greatly its IRS integration. In medium-size cities from the rest of the province, this was not the case. However, the formation of a national coalition between different sectors of what is now called the "popular economy", forced the enactment, in the context of a new crisis, of a Social Emergency Law, which includes a Complementary Social Salary (CSS) equivalent to a half of the minimal wage among its main features. In this paper, we recap these recent changes and we use the InteRa framework in a study case to measure how they influenced, along with academic and civil society support actions, the IRS integration in an intermediate city of Buenos Aires province. Our results show that the inclusion of the IRS improved fast after the availability of the CSS. Nevertheless, we registered a hard-to-overcome stagnation in some indicators of the InteRa framework, related to the weak engagement of the local municipal government with the IRS. Importantly, the CSS advent was not reflected in any indicator because there is no specific action related to this aspect in the InteRa framework. This may give an insight into future methodology improvement.

Keywords: Informal recycling sector; Developing countries; Popular economy; Argentina

1. Introduction

Waste management (WM) is today considered a key component of the circular economy (European Commission, 2015) and an entry point for sustainable development (UNEP and ISWA, 2015). At the same time, it is highly accepted that WM is mainly a regional and local issue subject to legal arrangements and political will, which needs adaptation to geographical characteristics, current environmental baselines (Brunner and Fellner, 2007), social and cultural specificities (Villalba et al., 2020), and resources and technology availability. Therefore, the goal of globalizing the circular economy (Geng et al., 2019) will depend on the development of well-contextualized sustainable waste management systems.

In the Global South, the transition to an integrated and sustainable waste management (Risso Gúnther and Grimberg, 2006; ISWM; UNEP and ISWA, 2015) should be based on the empowering and the working with the informal recycling sector (Diaz, 2017; Gutberlet, 2010; IRS; Velis, 2017; Velis et al., 2012). The IRS has been defined as those "individuals or enterprises who are involved in recycling and waste management activities but are not sponsored, financed, recognised, or allowed by the formal solid waste authorities, or who operate in violation of or in competition with formal authorities" (Scheinberg et al., 2010a, p. 4). Throughout the world, the IRS is composed of millions of waste pickers which are responsible for the relatively high recycling rates found in low- and middle-income countries (Scheinberg et al., 2010b; Wilson et al., 2012).

In the Latin America and the Caribbean (LAC) region, rapid urban growth, structural poverty, and repeated economic crises have made of waste picking a subsistence activity for an important number of people. The *Regional Evaluation on Urban Solid Waste Management in LAC* (Tello Espinoza et al., 2011) found a strong correlation between the poverty and indigence levels of countries and the number of waste pickers per inhabitant. The same correlation was found between the unemployment rate and the number of waste pickers per inhabitant, while it was also stated that during an economic crisis, the number of waste pickers grows fast (AVINA, 2013; Tello Espinoza et al., 2011).

In Argentina, the 2001 crisis enlarged the IRS population and triggered profound transformations in its structure (see next section). While in large cities like Buenos Aires this resulted in advanced inclusion of the IRS (EIU, 2017; Schamber, 2012), this was not the case in intermediate cities. However, recent changes at the national level related to the conformation of an alliance of different sectors of what is called the "popular economy" (Pérsico et al., 2017) are opening new opportunities for IRS integration in medium-sized cities.

Different methodologies to measure IRS integration in waste management systems exist (EIU, 2017; Velis et al., 2012). Between them, the InteRa framework (Velis et al., 2012) allows a simple and rapid evaluation of the interventions done or planned and its visualisation.

Thus, the objectives of this study are to recap the recent evolution of the IRS as part of the "popular economy" in Argentina and to evaluate, through the InteRa framework (Velis et al., 2012), how this has impacted, along with academic and civil society support actions, on the IRS integration of an intermediate city of Buenos Aires province.

In the next sections, we first briefly describe the recent evolution and current situation of the IRS in Argentina. Then, we describe the methods and the case study. Finally, we present and discuss the results of the study, before the concluding remarks.

2. Brief historical framework

Informal recycling has been present in Argentina since the XIX century (Schamber, 2010), as it was the case -at that time- in other regions now considered developed (Velis et al., 2009). After running unregulated for a long time, the IRS activity was forbidden in Buenos Aires city during the last military dictatorship (1976-1982), when engineered landfills and the privatization of waste services were promoted (Schamber 2010). Expulsed to peripheral municipalities, the IRS decreased its activity during some decades, but reappeared in the '90, when unemployment started to grow (ibidem).

A turning point in the history of the Argentinian IRS took place in 2001, after an economic crash with numerous political (Argentina had five presidents in two weeks) and social consequences. Indeed, the percentage of households under the poverty line in 2002 raised to 41.4% while the indigence level reached 18%. These factors, along with the Argentinean peso devaluation that increased the price of recycling materials, favoured a sharp increase in the number of *cartoneros* (waste pickers) (Chronopoulos, 2006; Schamber, 2010), which grew -only in the “Gran Buenos Aires”- from 25,000 to 40,000 (AVINA, 2013).

This ebullition period of the informal recycling activity in Argentina coincided with and was followed by a period of institutionalization and networking of the waste picker organizations. The horizontal and regular contact already existing between waste picker cooperatives in Buenos Aires city (Fajn, 2002) and a series of events organised by government actors, universities, and international institutions (Schamber, 2010) served as stepping stones for an improved IRS organization. Rapidly, coordinated efforts between these actors resulted in the repeal of the law that forbade the IRS activity and the enactment of a new one that recognized the *cartoneros*’ job in 2002.

From the interaction between *cartoneros* and popular and neighbourhood assemblies that emerged during the 2001-2002 crisis, a heterogenic *cartonero* grass-root movement was formed, with non-waste picker leaders (AVINA 2013). An early action of this movement was the foundation of the Excluded Workers Movement (MTE). Developed upon the organization of the *cartoneros*’ work, the MTE gradually extended its action boundaries to reach other sectors of what, later in time, would be called the “popular economy” (PE) (Grabois and Pérsico, 2015). This concept is built on the basis of broader and pre-existing definitions (Coraggio, 2018, 1993) and refers to the activities of those productive units related to a subsistence economy, where: a) means of production are detained, exploited, and -in many cases- created by workers; b) the workforce is the most important component of value creation; c) there is no business rationality nor accumulation logic (Grabois 2016). It includes (Grabois and Pérsico, 2015) peasants, waste pickers, ambulant vendors, artisans, delivery men/women, labourers of recovered factories (i.e., a closed down factory re-opened by its workers), domestic workers, and tailors, among others, but excludes wage employees and employers.

In 2011, after several years of economic growth and empowerment of trade unions (Fernández Mouján et al., 2018), the MTE and other associations founded the Confederation of the Popular Economy Workers (CTEP), a trade union for workers of the popular economy. From this moment onwards, the evolution of the IRS in Argentina can be better understood in the context of the popular economy struggle.

New crisis and new opportunities

In early 2016, through a very innovative resolution (Grabois, 2016), the CTEP was legally recognised by the Argentinean government as a complementary trade union for non-dependent workers of the popular economy. This resolution had multiple implications, as it allowed the CTEP to represent the collective interests of these workers, to create its social care program, and to promote its inclusion in the pension system, among other benefits (Fernández Mouján et al., 2018).

In the context of a new economic crisis with similar causes to those of the 2001's, the CTEP organized, by the end of 2016, important protest rallies, which led to the enactment of a Social Emergency Law. This law institutionalized two main tools: on the one hand, a Complementary Social Salary (CSS) to workers of the popular economy which included both organized and not organized waste pickers, and which was half the national minimum wage; on the other hand, a National Register of Workers of the Popular Economy. At the end of 2018, 271.00 people received the CSS (ANSES, 2018).

In what follows, we analyse how the evolution of the IRS situation in Argentina, along with the intervention of different actors accompanying the waste pickers organization after 2015 (see Results), allowed for important changes in the integration of the IRS into a medium-size city of Buenos Aires province, Tandil.

3. Materials and methods

The information upon which we analyse this study case was obtained as part of a transdisciplinary work started four years ago, in which scientific knowledge co-evolved with the IRS of Tandil. Throughout these years, we combined qualitative research methods, like interviews or participative observation, with quantitative tools, like material flow analysis (see Figure 4). For the evaluation of the evolution of the IRS integration presented here, we used the following specialized methodology.

The InteRa tool and framework

The *integration radar* or InteRa (Velis et al., 2012) is a tool used for the evaluation and improvement of the degree of integration of the IRS into the SWM system of a city. It is based on a conceptual framework that considers four categories of intervention to boost the IRS (see Figure 1). Three of them are based on the interfaces between the IRS and the "outside world" (A: with the formal SWM system; B: within the value chain, and; C: with society as a whole). A fourth category underpins the others by grouping actions that facilitate the fulfilment of interventions in the others (O: Organisation and empowerment).

Each interface groups several *intervention points*, i.e., key factors that can improve the role of waste pickers in the formal SWM system and/or improve their living conditions, which are evaluated by the degree of existence or consideration of some *specific actions* (SA) that should allow for the achievement of the *intervention point*.

InteRa translates the framework evaluation into four sustainability indicators by measuring the importance or consideration of each interface or *intervention category* in a study case. Each indicator is constructed by averaging the scores of its inner *intervention points*, who are calculated, in turn, as the arithmetic mean of *specific actions*' scoring. At this lower level, a qualitative assessment of each SA is translated into three possible numerical scores: a) 1, if the SA is "treated as a key action"; b) 0,5, if the SA is "considered to a medium degree", and; c) 0, if the SA is ignored or if no information is available. Therefore, the intervention point score and the four main indicators are bounded between 0 and 1. Finally, the four main indicators are represented in a radar diagram.

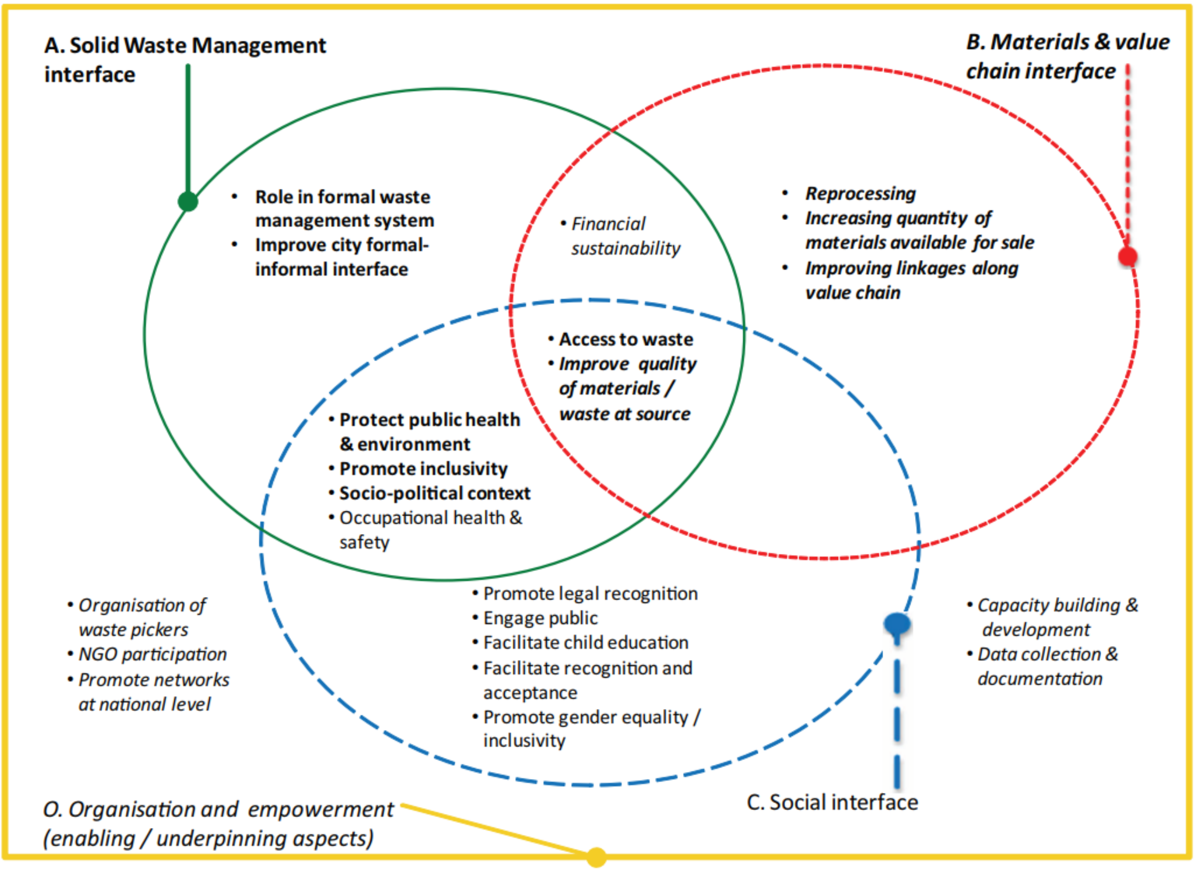


Figure 1: InteRa analytical framework and typology of interventions. Source: Velis et al. (2012).

The InteRa framework has been applied to 10 cities in Velis et al. (2012), in an illustrative manner, and to the Sorocaba City in Brazil (Silva de Souza Lima and Mancini, 2017). Therefore, it is the first time that this methodology is applied to an Argentinean city.

Case study: the IRS of Tandil

Tandil is a city located at the southeast of Buenos Aires province (see Figure 2). With an urban area of 50 km2 and 128.900 inhabitants (INDEC, 2015b), the city follows a sprawl model of growth (Fernández and Ramos, 2013).

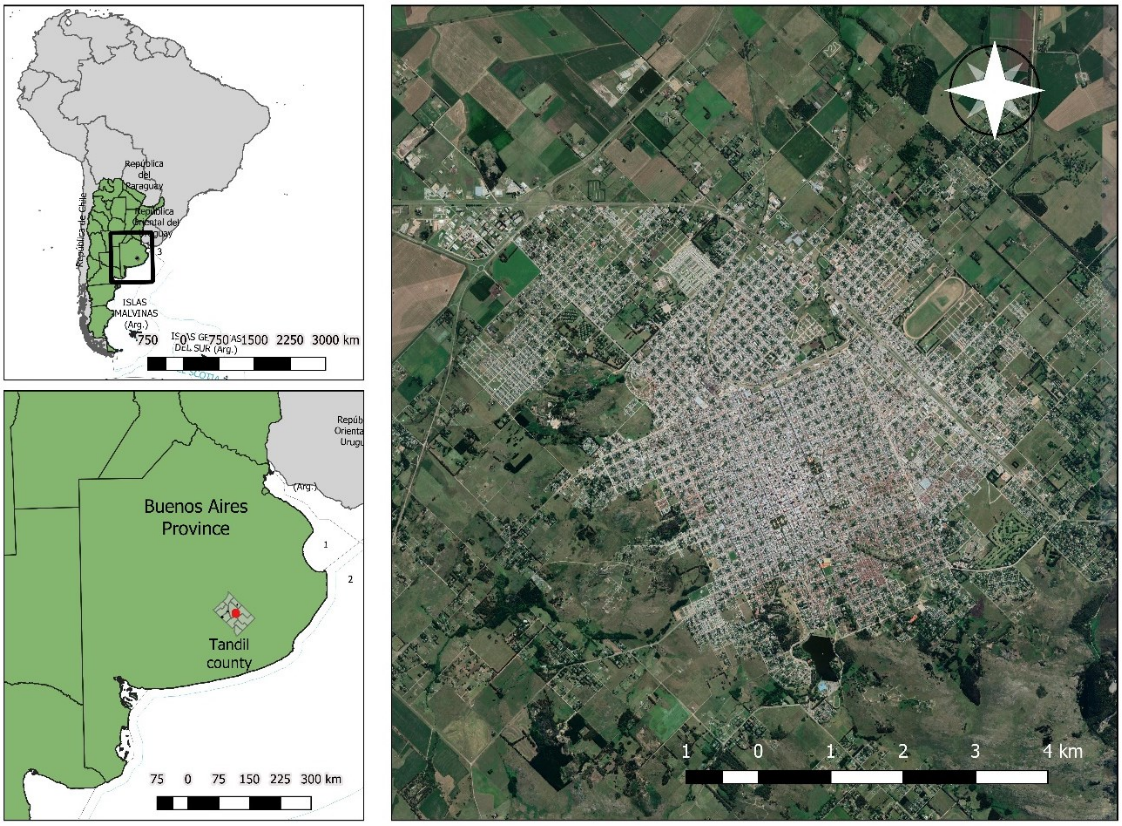


Figure 2. Study area. Buenos Aires province in the black square on the upper-left and in the bottom-left box, where the county of Tandil is presented with Tandil city in red. In the right box, Tandil city.

The presence of waste pickers in Tandil has been registered for decades. In 1995-1996, 77 waste pickers were censed, who had no income other than the commercialization of recovered materials (García, 1999). Before the construction of the first sanitary landfill in 1998, solid waste was disposed in an open dump where more than 30 waste pickers worked daily, and some families lived permanently.

As it was the case for Buenos Aires city, the IRS of Tandil was, for a long time, ignored before being excluded. The construction of the first sanitary landfill clearly shows how this mechanism worked: the existence of waste pickers was denied by the authorities of the time (García 1999); however, when they prepared the bidding for the construction and management of the sanitary landfill and the closure of the old open dump, they set for the ban to waste pickers to operate in both places (ibidem).

Before the beginning of our investigation in 2015, no other register of the waste pickers' activity in Tandil could be found in our literature review. However, we learnt, through interviews to current *cartoneros* and to key actors, that street waste pickers continued their activity and that, once the old open dump was closed, waste pickers avoid the private security of the landfill to recover materials, with a tacit acceptance of the municipal and the private company authorities.

In recent years, a disregard of the IRS prevailed. In 2009, the Children Hospital Foundation started a plastic bottle recovery program; the following year, the Taller Protegido -i.e., a non-profit organization aiming at the inclusion of people with disabilities- copied this strategy and in 2013, an association aiming at the care of children with rare diseases started a paper and board recovery campaign with the support of the municipality. These organizations never considered the involvement of the IRS in their projects. In the case of plastic, *cartoneros* did not collect it because local buyers would not want it, but in the case of paper and board, they constituted their main working material.

These aid-related recycling programs were very successful, which pushed the municipality to open, in 2015, the first Clean Point, i.e., a facility where citizens could dispose their recycling materials. Every material received was then destined to a different non-profit organization. These organizations also benefited from a free trip by train to Buenos Aires, which allowed them to sell the materials at better prices. Waste pickers were not considered in the Clean Point dynamic and were subdued to middlemen conditions.

Analysis phases and evaluation points

To analyse the impact of the changes in the IRS integration in Tandil and to explore possible future improvement paths, we defined four moments to apply the evaluation methodology: three of them in the past, i.e. an *ex post* analysis of each baseline situation (Velis et al., 2012), and one of them in the present, i.e. an *a priori* analysis, together with a search of ways of improvement (ibidem).

We started our work with the IRS of Tandil in 2015. Since the evolution of the IRS had ups and downs during the period of study, depending on where we stated the baselines to run the evaluation, our results will differ. We can identify three distinct cycles of the IRS evolution: in the first cycle, some degree of IRS organization was achieved before an internal collapse; in the second one, the IRS was reorganized under the MTE orbit (see Brief historical framework), followed by a rapid growth and major achievements; and a current but not-finished third cycle, upon which to explore possible future paths.

We decided to situate baselines before our intervention, as well as at the beginning/end of each cycle followed by the IRS, as described in Figure 3.

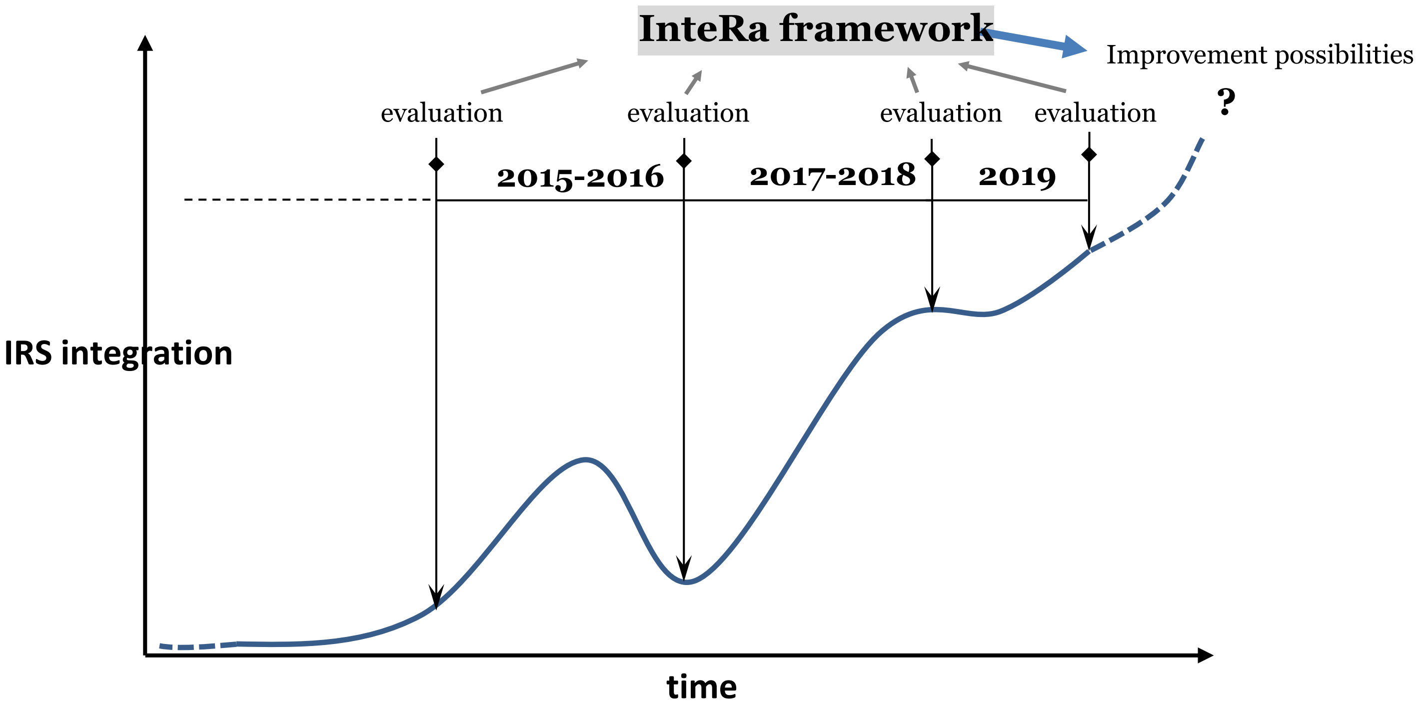


Figure 3: Phases of analysis and evaluation moments.

4. Results and discussion

2015-2016: External support, cooperative formation, visibility and internal breakdown

In 2015, former members of an NGO, who were in contact with some street waste pickers, offered them help to establish a cooperative together. They asked for support to the local university, where our research centre had an incipient project on urban waste management.

While progress in the legal aspects advanced fast, the cooperative structure remained very weak, with only four waste pickers and four non-waste pickers members. They did not even count with a working facility, but just a temporarily conceded space at a "recovered factory". We therefore planned a university extension project (Arocena and Sutz, 2005) i.e., an action and territory-oriented project based on mutual learning and co-production of knowledge. The project involved prospective workers of the cooperative (waste pickers and non-waste pickers), students, and researchers. Its main objective was to make the IRS role in WM visible through the implementation of a waste source-segregation experience in a neighbourhood of Tandil.

The pilot experience started by the co-designing of an information flyer by waste pickers and students and followed by its door-to-door delivering. The collection of a broad range of materials was performed by waste pickers and researchers. The program was successful but ended abruptly for two main reasons: a) the neighbourhood was near the cooperative headquarters but far from the usual waste pickers working routes; b) most collected materials (plastics and glass) were not bought in Tandil. Therefore, they were stocked for future sale, which not only was not compatible with their subsistence economy but also prevented the arrival of new waste pickers to the cooperative.

In the late 2015, we organised a workshop with actors from the different recycling projects/organizations as well as the Municipality. The objective of this workshop was to create a participative vision of the recycling sector of Tandil for 2030 through back-casting. Unfortunately, the Environment Department director missed the workshop, although she had confirmed its participation. For the remaining participants, her absence meant a lack of commitment of the local government with the issue at hand.

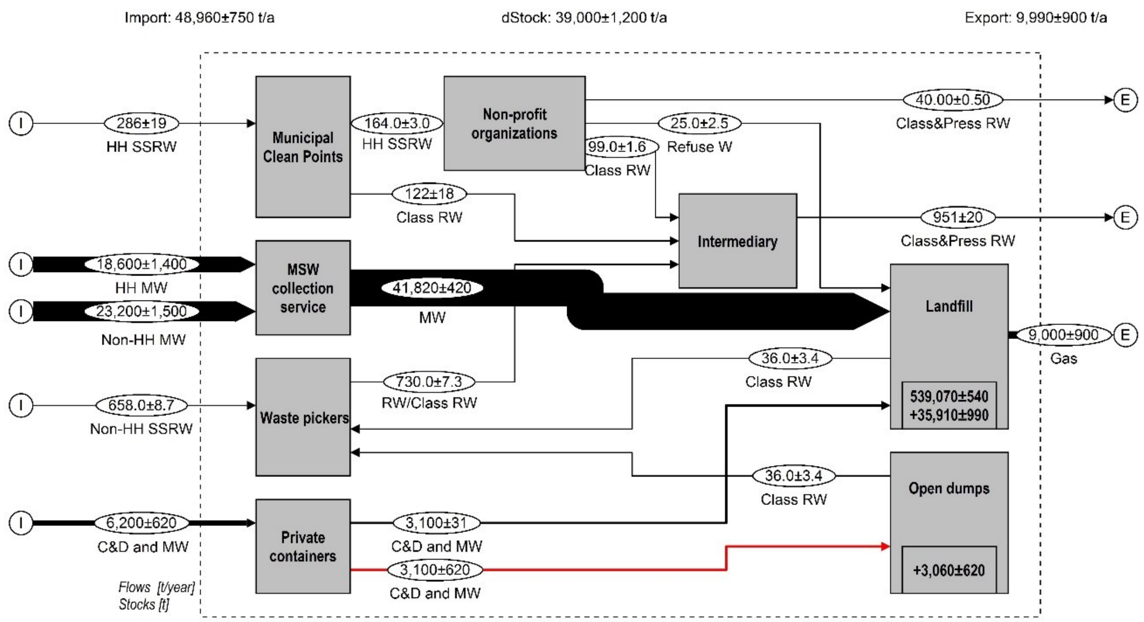
During 2016, the cooperative gained popularity through press appearances (e.g., El Eco de Tandil, 2016). The launching of “Mesa GIRSU”, i.e., a boundary organization (Guston, 2001) composed of elected councillors, the university, associations, and informal actors, constituted a new pressure platform for IRS integration. Although the local government refused to participate at Mesa GIRSU, it agreed to have some meetings with cooperative representatives and, when the second municipal “Clean Point” was launched, the Municipality offered them its management. This offer was accepted but, unfortunately, the cooperative collapsed a short time later as a result of social conflicts between its members.

2017-2018: MTE connection and cooperative re-launching, IRS recovery indicators, CSS

Despite the achievement of its legal constitution, the cooperative was inactive for several months. Meanwhile, the 2015-2016 experience allowed us to finance a new and broader project under a cooperative promotion funding call. The objectives of this project were to analyse the possibilities of the IRS in Tandil based on a local WM system characterization (Villalba et al., 2020) and on IRS experiences in other cities of Argentina, mostly Buenos Aires.

A project member, who had travelled to Buenos Aires to visit MTE recycling cooperatives to gain knowledge on best practices, became the promoter of the cooperative re-foundation, under the launching of the MTE Tandil. This confirms what Fernández Álvarez and Carenzo (2012) signalled for other action-research projects with IRS in Argentina i.e., the existence of a permeable frontier between the academia, NGOs, and organizations under study.

As part of the new project, we performed a Material Flow Analysis of the WM system for the year 2016, obtaining the first IRS recycling indicators (CINEA, 2017). These results showed that the IRS recovered much more material than the formal recycling circuit. This information was used by MTE authorities in many opportunities when demanding official support (see for example LOT, 2018). A detailed analysis -including uncertainty considerations- for the year 2017 is now available (Villalba, 2020a), which estimates that the IRS recovered, without counting metal scraps, 1.7 ± 0.1 % of solid waste generated, against 0.6 ± 0.07 % of the municipal strategy (see also Figure 4).



HH SSRW = Household Source-Separated Recycling Waste; HH MW = Household Mixed Waste; RW=Recycling waste; Class RW= Classified recycling waste; Class&Press RW= Classified and pressed recycling waste; C&D= Construction and demolition waste; MW=Mixed waste

Figure 4. Waste flows in the solid waste system of Tandil for 2017. Source: based on Villalba (2020a).

The Complementary Social Salary (CSS) allowed for the incorporation of a large number of members to the cooperative. Moreover, it served to organize those waste pickers working on the sanitary landfill. The cooperative, with 24 inscriptions to the CSS in 2017, had 116 inscriptions by the end of 2018. However, not all of them effectively accessed to the CSS and others where deregistered later (see Figure 5). In the first case, this was because some of them did not qualify for the CSS (e.g., they had an official employment). In the second, because inscriptions included people not working as waste pickers or that decided to stop this work. Figure 5 shows how the inscriptions to the CSS evolved and how many of these inscriptions are active today.

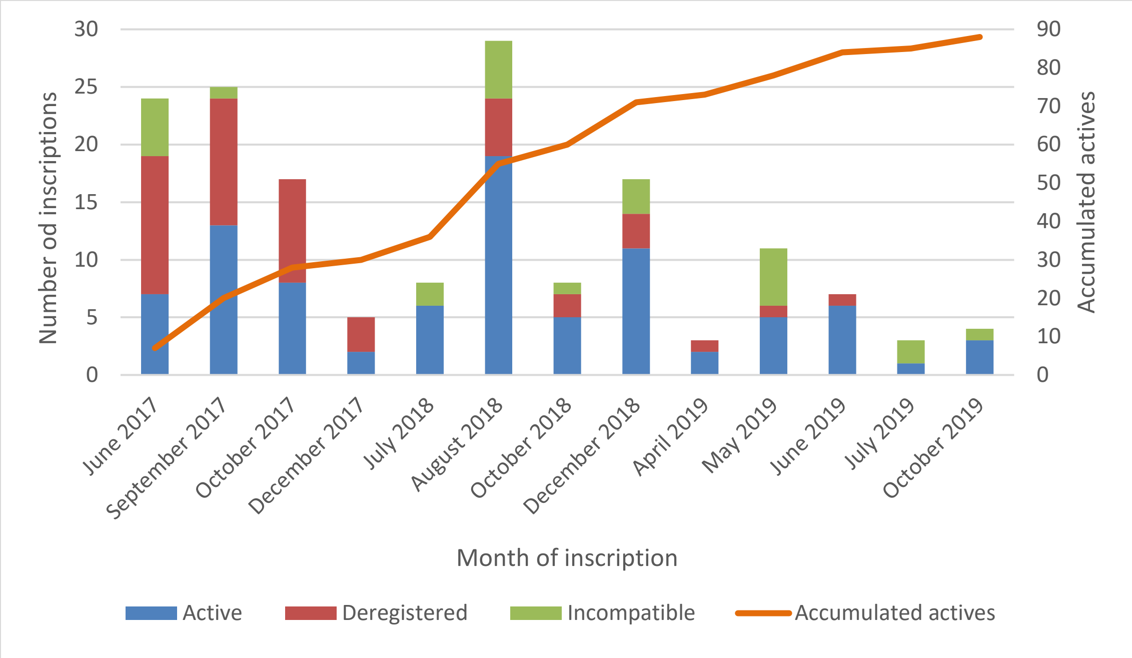


Figure 5: Evolution of the inscriptions to the CSS since its beginning and the current total number of active members. Source: the author, based on Cooperative's registers.

Another feature of the MTE connection and the CSS existence was the beginning of the *Promotoras Ambientales* (Environmental Promoters) program in Tandil. In this program, which was originally from Buenos Aires, recycler women raise awareness of the waste pickers' job, source separation, and the importance of inclusive recycling, by visiting the city community door-to-door, while retrieving data about household members predisposition to separate recycling materials.

After five months of a public campaign demanding a working shed to the local government, the authorities finally accepted to award a rent subsidy to the cooperative. Finding and conditioning the new place took several months. Moreover, the cooperative received no income apart from the rent subsidy because associated waste pickers needed to sell their materials day-by-day to middlemen, and, to commercialize materials directly to industry, high stocks were needed. However, some materials such as plastic, which were not bought by intermediaries, started to be collected by waste pickers and stocked in the shed. This, along with materials furnished by citizen and some institutions, constituted the stock for the first sale (see next section). On the other hand, the local university contributed with an industrial scales and part of the electrical installation materials for the cooperative through different projects, among other supports.

At the landfill, after a conflict managed in part by the MTE, an agreement was signed between authorities and waste pickers, providing them with an entry permit at specific timeframes.

2019-: Recent advances and actual baseline

The conditioning of the shed constituted a plateau in the development of the cooperative. Once it was resolved in the early 2019, the basis for important changes was established. This new period started with the acquisition of a multi-material compactor, which was possible thanks to the financial aid of the MTE.

Some months later, in July 2019, a first collective sale of more than 30 tons was made (see Figure 6). This sale allowed for the collection of enough funds to start paying, on a weekly basis, the materials collected daily by some of its members, which was done at a much convenient price than they had with the middlemen. Moreover, as the prices obtained by the cooperative through the MTE in Buenos Aires are better than the prices obtained by local associations collecting recyclables, the cooperative started to commercialize most of the materials arriving to the municipal Clean Points. Also, a local enterprise started to buy HDPE to the cooperative. Figure 6 shows the amounts of recycling waste recovered by the waste pickers and commercialized through the cooperative in 2019. Importantly, this is only a fraction of materials recovered by waste pickers, because most of them are still selling the materials daily to middlemen.

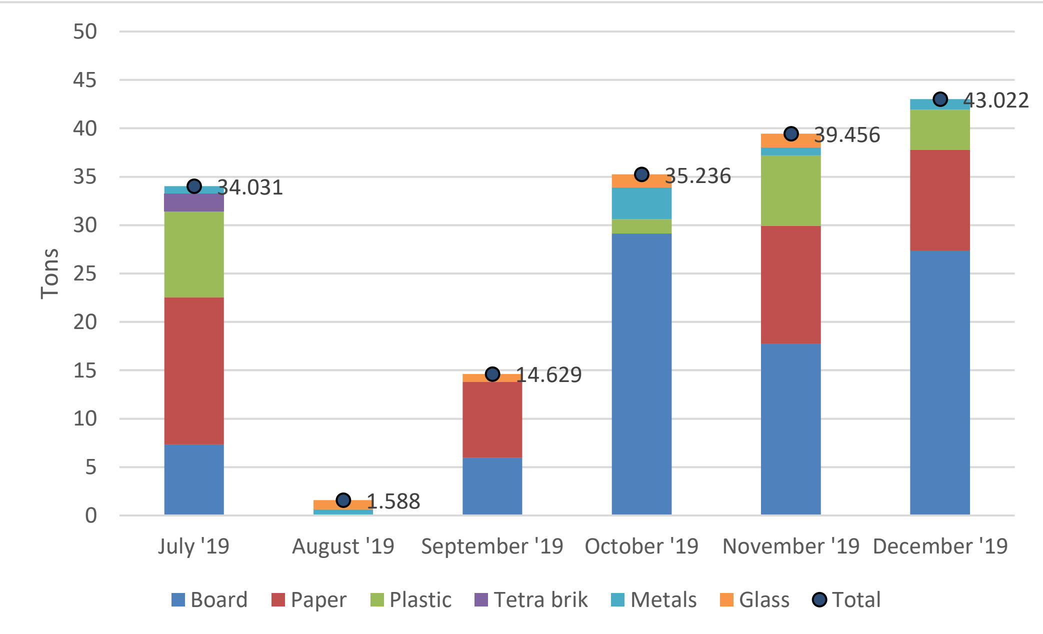


Figure 6: Tons of recycling materials recovered by the waste pickers and commercialized through the cooperative in 2019. Source: CRUT MTE (2020), based on sell registers.

Today, the cooperative has 88 active members, out of which 32 work in the landfill while the remaining work in the streets and the shed. They also managed to have a primary school running in the shed, as many of its members have not finished their elementary school studies.

On the other hand, a waste pickers' census is being performed with university support. At the same time, the Humanities School in campus started a source waste separating program based on inclusive recycling which, in 2019, recovered 2 tons of recycling waste (mostly paper) for the cooperative (CRUT MTE, 2020). In the context of this project, the *Promotoras* are training students as well as faculty and staff.

InteRa results

Figure 7 shows the evaluation of the moments indicated in Figure 3 through the InteRa framework (see also Supplementary Information). In the first baseline situation (2014), we observed advances in the Organisation and empowerment (O&E) and SWM Interface (SWM-I) indicators. The reasons for this positive result are the existing legal frameworks at province and national levels recognising waste pickers and stating their inclusion in waste management plans; the existence of waste pickers' networks at a national level; the first NGO participation; and the IRS of Tandil non-dependency on external financing.

At the end of the first study period (2015-2016), little progress was measured in the O&E, which corresponds to the cooperative organisation tentative and the participation of the university in a training course. The possibility of managing a new municipal Clean Point by the cooperative at the end of the period, public awareness, and documentation of the IRS role by the university are responsible of the progress registered in the SWM-I. No progress was registered in the other two interfaces.

Figure 7: Evolution of the InteRa indicators during the phases of analysis.

In the third period (2017-2018), qualitative changes were measured in most axes. These changes are mostly associated, on the one hand, to the MTE connection and the CSS beginning, and, on the other hand, to the strengthening of the university support. In the SWM-I, the higher visibility of the cooperative improved its acceptance and recognition by society and authorities alike, while new research stated the importance of the IRS in local material recovery. In the Materials and Value Chain Interface (M&VC-I), changes were very important and related to storage space availability, the expanded range of materials to be commercialized, better knowledge on how to segregate waste following the MTE instructions, and the direct contact with industries provided also by the MTE Buenos Aires.

The Social interface (S-I) indicator, that valued zero the past periods, reached the other indicators. Again, the MTE underpinning provided know-how and recommendations related to the internal work organization, the advancement of educational offers to cooperative members and the recognition of the IRS role through programs such as the *Promotoras Ambientales* program. Moreover, the recognition of the CTEP as a union trade first and the CSS later, confirmed the recognition of waste picking as a profession.

Finally, the O&E indicator showed little progress in this period. In part, it corresponds to a reduction in the punctuation of the Financial viability intervention point, as the cooperative was dependent on the municipal subsidy to the shed renting at the end of the period. Also, this may be explained in part by the effort made during this period in the exploitation of the already existing potential, allowing for the progress on other aspects but inhibiting the development of new empowering actions. However, it is important to note that for the first time, a harmonic integration of the IRS was achieved, that is, similar in all axes, as recommended by Velis et al. (2012).

The last evaluation corresponds to the 2019 first semester. A stagnation in the SWM-I indicator can be seen, which may be due to an inherent limit in the progress of this indicator without an active participation of the municipality (see next section). In the M&VC-I, progress was possible thanks to the incorporation of the press to densify waste, to the contact with a local industry which started paying for HDPE collected by the cooperative, and to the beginning of source segregation campaigns by self-organized citizens in some local neighbourhoods. In the Social-I, the improvement is related to the acquisition of uniforms, identification cards, and safety equipment through the MTE. Finally, in the O&E, the first material sale to Buenos Aires, which improved the understanding of secondary raw material specifications, along with the recording of physical and monetary flows, marked a significant increase of the indicator. Importantly, this indicator is more sensitive to changes because it is composed of less specific sub-indicators of actions taken.

Future paths for IRS integration: Who is who in the InteRa framework

The analysis of this evolution seems to show that progress in the IRS integration is pulled by the Organisation and empowerment axe, as signalled by Velis et al. (2012). The new advantage in the O&E-I indicator in the last evaluation may therefore indicate that future improvements are possible. However, when analysing *who* promoted the specific actions considered or fully implemented (see Supplementary Information), we can see that the local government is mainly absent or that, after long requesting, it has *conceded* some *benefits* but not *recognitions*.

Regarding the SWM-I, room for improvement is largely conditioned by several factors. These factors are the willingness of the local government to grant the IRS full access to Clean Points and to better organize work at the landfill, and the advancement of a source-separated collection. The reason for this need of government involvement is that such an action cannot be organized by households or commerce and waste pickers only. In the M&VC-I, there are improvement opportunities related to the reprocessing of materials, where the cooperative can make some progress with the support of the university (see for example Carenzo, 2017). In other aspects, such as the organization of middlemen, municipal action is needed. In the Social-I, most of the specific actions are "considered to a medium degree". However, when analysing *who* promoted these specific actions, we see that they are the result of the *Promotoras*' awareness actions, the MTE providing uniforms and other support, or the cooperative organizing a primary school for its members. Full implementation of these SA will most probably need the local government intervention. In the O&E, there is still room for improvement in terms of capacity building through courses and the improvement of the financial viability.

Finally, it is important to consider that in many specific actions, continual efforts for needs fulfilment, as well as support from the university in documenting and raising concern about the role of the IRS can all end when research programs finish or change their focus. Consequently, the institutionalization of these measures may be important.

5. Conclusion

The integration of the waste pickers as part of the "popular economy" and its main tool, the Complementary Social Salary (CSS), constitute a new milestone in the Argentinean IRS history. Even if it is probably too early to fully evaluate the effects this instrument had in the IRS organisation, the use of the InteRa framework allowed us to measure its beneficial impacts in Tandil city. Moreover, it permitted us to explore improvement paths and to identify progress obstacles.

One of the main issues to overcome is how to open and maintain communication channels with local authorities to co-design joined actions and integrated waste management policies. Replicating the national model of integration with other sectors of the popular economy may be an adequate strategy to address this challenge at the local level.

The InteRa framework could also be used to compare how the CSS impacted in other intermediate cities of Argentina. However, it is important to note that the CSS advent is not reflected in the O&E-I indicator because there is no specific action related to this aspect in the framework. This may give an insight into future methodology improvement.

More generally, further research may explore if alliances of self-employed sectors as the Argentinian popular economy are desirable and/or possible in other countries of the Global South. These sectors, together with some often-non-remunerated activities (e.g. care activities), cover most of the population necessities. They can provide, therefore, the foundation of a new economic organization based on the full recognition of their work.

Declaration of conflicting interests

The author declares no conflict of interests.

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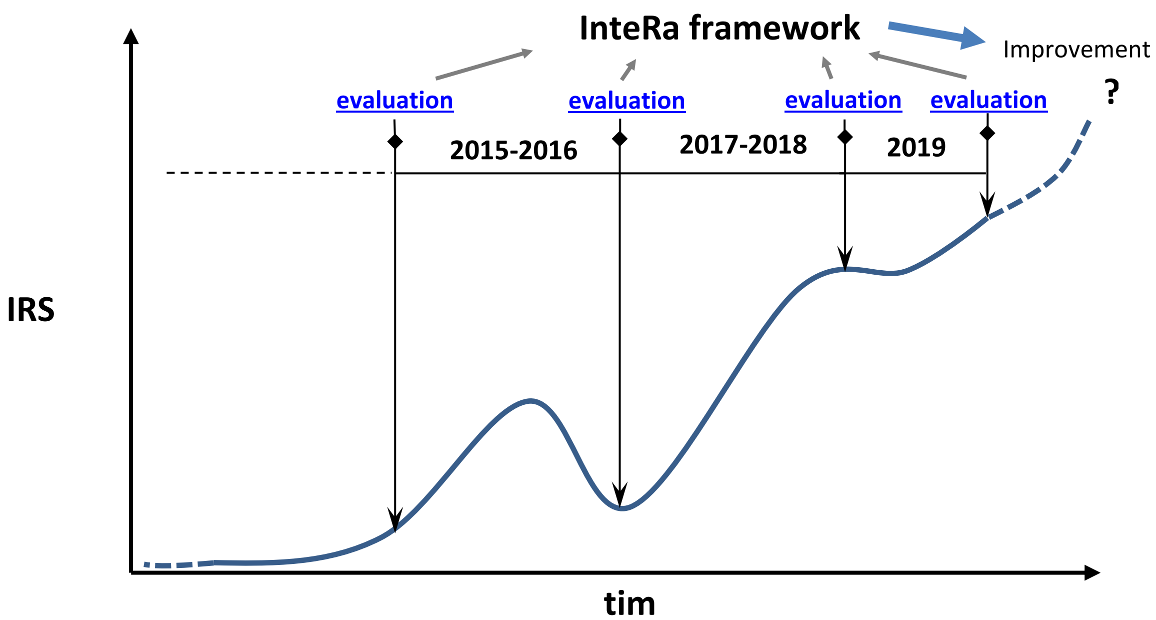
Supplementary information

Here we present the application of the InteRa framework to evaluate the evolution of the integration of the IRS in Tandil (Buenos Aires). Originally, this form part of a spreadsheet. Here we copy the tables and obtained results. In the original file (attached to the CD of the Ph.D.) it is possible to check formulas.

Organization of the evaluation tables

For each evaluation table (one for each period: 2014; end 2015-206; end 2017-2018; 2019; see graph below), we transcribed the framework constructed by Velis et al. (2012). We added an Observations column, in which we explain the reasons for the score we gave -in each case- to the related Specific Action. As determined by the tool, all other scores are all calculated automatically. When a score from a Specific Action changed concerning the previous evaluation, the cell is painted in green for an increase and in red for a decrease.

For the results and results analysis, see the original article.



2014

Score	Interface	Score	Group of interventions	Score	Intervention points	Score	Specific actions	Observations
0.1875	**A - Solid waste manageme nt (SWM) sector interface**	0.167	Access to waste	0.333	Access to waste	1	Legal recognition of the right of pickers to collect waste, sell the materials separated and keep the income	The national law 26.916 of Minimal Budgets to Domestic Waste Management of 2002, in its Article 25 c) determines that the Authority of application of the law "must promote the integration of informal waste collection systems". In addition to the national law 26.916 (see row #1), the Buenos Aires province law 13.592 from 2010 establishes the basic features of the Integrated Waste Management Policy of the province and states in its 3rd article: in point 3), the consideration of waste as resources; in point 6) the principle of SW valorization, and; in point 10) "the economic exploitation of waste, aiming at the the generation of employment in optimal health conditions as a relevant objective, paying special attention to the situation of informal garbage workers"
						0	Waste pickers to have controlled access to waste at collection points	The existence of waste pickers in Tandil is denied by local authorities
						0	Waste pickers to have controlled access to waste at transfer stations, disposal sites or other waste facilities	Waste pickers enter to the landfill but without any agreement. Working conditions are precarious.
				0	Role in formal SWM system	0	Inclusion into/ integration with formal SWM sector collection	The existence of waste pickers in Tandil is denied by local authorities
						0	Inclusion into/integration with formal SWM sector transport	The existence of waste pickers in Tandil is denied by local authorities
						0	Official role in providing recycling within formal SWM system	The existence of waste pickers in Tandil is denied by local authorities
		0	Recognising role of informal sector in SWM	0	Socio-political context towards informal sector	0	Institutionalising policies regarding IRS (so that they become robust to political shifts)	The existence of waste pickers in Tandil is denied by local authorities
						0	Documenting the role and advertising benefits provided by IRS within the wider SWM system (acknowledgment of their role and contribution)	A local NGO have made a fisrt approach to local waste pickers but there is no attempt to document their role in the SWM system
				0	Promote inclusivity	0	Involve all stakeholders in SWM planning	SWM planning is carried by the local governement in isolation
						0	Institutionalise inclusivity of informal sector	The existence of waste pickers in Tandil is denied by local authorities
		0.333	Protecting public health and environment	0.333	Protecting public health and environment	0	Control sorting in the street and ensure that residues after sorting are disposed of properly	Waste pickers work in isolation, there is no rights nor rules for them
						0	Regulate handling of hazardous wastes	Waste pickers work in isolation, there is no rights nor rules for them
						1	Promote the collection and disposal of waste from marginalized/low-income areas	The collection of SWM has a 100% coverage
		0.25	Strengthening interfaces	0	Improving formal	0	Smoothing take over from households or from waste collectors to the IS	Waste pickers work in isolation, most of them without any contact with landfill authorities or with households

					SWM/informal interface	0	Easing take over from IS to municipalities or private contractors for secondary transport and final disposal	SWM collection is municipal and final disposal is carried out by a private entreprise. There is no contact between waste pickers and these actors
				0.5	National policies improving formal state/informal interface	1	National policies/legislation to promote recycling (considering IRS potential contribution)	The national law 26.916 of Minimal Budgets to Domestic Waste Management of 2002, in its Article 25 c) determines that the Authority of application of the law "must promote the integration of informal waste collection systems"
						0	National strategies for the inclusion of IRS within SWM	There is no national strategy for inclusion of waste pickers. Progress in this aspect runs on behalf the local governments

0.058	**B - Materials and value chain interface**	0	Improving quality of materials for recycling at their source	0	Improving quality of the source materials/ reducing crosscontamin ation	0	Source segregation	There is no segregation at the source
						0	Contracts with waste generators	Waste pickers don't work collectively
		0.175	Adding value to the secondary raw materials/prod ucts sold	0.25	Increasing quantity available for sale	0	Use of larger containers/bags by IRS collectors	Waste pickers work in isolation, there is no systematic collection system
						1	Use of wheeled containers by IRS collectors	Most of waste pickers use wheeled containers
						0	Make storage space available	Waste pickers work in isolation, they don't have conditioned separation sites
						0	Expanding the range of materials recycled	Materials recycled by waste pickers are those accepted by local middlemen. There is no intervention of the local government
				0.1	Reprocessing	0.5	Segregating collected materials into distinct categories	Some waste pickers classify their waste at home, others not. Plastics are not commercialized. They don't have the knowledge to dissasemble a computer
						0	Washing/ removing contraries and contaminants	Waste pickers don't have acces to cleaning facilities. Moreover, plastics are not commercialized
						0	Densification (to decrease transport costs and increase density)	Waste pickers don't have acces to waste processing machines
						0	Processing to intermediate product	Waste pickers don't have acces to waste processing machines
						0	Manufacturing final products	Waste pickers don't have acces to waste processing machines
		0	Improving linkages along value chain	0	Improving linkages along value chain	0	Strengthening relation between IRS and recycling industries	Waste pickers don't have direct contact with industries. There is no mechanisms for dialogue with industries or private companies
						0	Contracts with specific middlemen/ recycling industry	Sales to middlemen are made without any formal agreement
						0	Bypassing middlemen	Waste pickers don't have direct contact with industries
						0	Organising middlemen	There is no intervention of the local government

0	**C - Social aspects and interfaces with society**	0	Facilitating recognition and acceptance of the IS	0	Promoting legal recognition	0	Issuing of birth certificates and other legal documents	Waste pickers work in isolation, there is no rights nor rules for them
						0	Rights and duties: right to vote, land property rights, duty to pay taxes, etc.	Waste pickers work in isolation, there is no rights nor rules for them
						0	'Light' regulations	There is no national strategy for inclusion of waste pickers. Progress in this aspect runs on behalf the local governments. The existence of waste pickers in Tandil is denied by local authorities
						0	Recognising wastepicking as a profession	There is no recognition of wastepicking as a profession
				0	Facilitating recognition and acceptance	0	Issuing of identity cards	Waste pickers are not provided with identity cards
						0	Provision of uniforms	Waste pickers are not provided with uniforms
				0	Engaging the public in the intervention	0	Through awareness raising campaigns	Public campaigns concern recycling project related to non-profit organizations and that don't consider waste pickers
						0	Through involvement in planning the intervention	SWM planning is carried by the local governement in isolation
						0	Through promoting source separation	There is no segregation at the source
		0	Work towards children, education, and gender equality and inclusivity	0	Facilitating child education	0	Work to eliminate child labour	There is no national strategy for erradicating child labour in the IRS. Progress in this aspect runs on behalf the local governments. The existence of waste pickers in Tandil is denied by local authorities
						0	Incentives to attend school	There is no national strategy for school attending of members of the IRS. Progress in this aspect runs on behalf the local governments. The existence of waste pickers in Tandil is denied by local authorities
						0	Providing schools for waste pickers' children	There is no national strategy for child school attending of members of the IRS. Progress in this aspect runs on behalf the local governments. The existence of waste pickers in Tandil is denied by local authorities
				0	Promoting gender equality/inclusivity	0	Involve women in planning and delivering specific interventions aimed at women	SWM planning is carried by the local governement in isolation. Waste pickers work in isolation, there is no rights nor rules for them
						0	Loans accessible to women	There is no accesible loans to women
		0	Occupational health and safety	0	Ensuring health and safety standards at work	0	Safety equipment	Waste pickers are not provided with safety elements
						0	Access to health care	Waste pickers have not access to health care
						0	Ensure hazardous waste sorted separately	Waste pickers work in isolation, there is no rights nor rules for them

0.278	**O - Enabling actions -**	0.5	Organisation of informal sector	0	Organisation of waste-pickers	0	Encourage organisation into groups, e.g. cooperatives, associations, CBOs, MSEs	Waste pickers work in isolation, they are not planning to work together

	organisation & empowerment			0.5	NGO participation	1	NGO participation— helping the IRS to organise and help themselves	In 2014, a local and recently launched environmental NGO decided to work with some cartoneros in a project that focused on schools. Without official support, they installed paper and board collection points in 20 schools, and contacted street waste pickers to pick up the materials. Unfortunately, the program was interrupted, for several reasons related to logistic costs and lack of coordination. NGO members knew that helping waste pickers to work together will result in better working conditions for them
				1	Promote networks on national level	1	Organising national forums and meetings	At the national level, organization of waste pickers is in an advanced stage. From 2012 they have the Argentinean Federation of Waste Pickers and from 2011 the MTE is part of the Confederation of Workers of the Popular Economy (see main article)
						1	Creating a national network of waste pickers	From 2012 they have the Argentinean Federation of Waste Pickers
		0.333	Financial viability	0.333	Financial viability	0	Access to capital for the IRS	The MTE managed to have access to capital to help cooperatives in formation stage but this help is not available for waste pickers of Tandil
						0	Reduce vulnerability to market shifts on prices of materials	Waste pickers work in isolation, there is no rights nor rules for them. There is no intervention of the local government
						1	Dependent on market revenues rather than governmental/ NGOs/project-related subsidies	Waste pickers are completly depending on market revenues
		0	Capacity building	0	Capacity-building and development	0	Training courses	Waste pickers don't have access to training courses
						0	Literacy courses	Waste pickers don't have access to literacy courses
						0	Involvement in intervention steering committee	Waste pickers don't have access to technical instruction
						0	Understanding buyer’s requirements (secondary raw material specifications to be met)	Waste pickers don't have access to technical instruction
				0	Data collection and documentation	0	Record keeping of workforce, tonnes collected, costs and earnings	Waste pickers don't keep records about tonnes collected, costs, etc.

Summary	
Solid waste managemet interface	0.188
Materials and value chain interface	0.058
Social interface	0
Organisation & empowerment	0.278

2015-2016

Score	Interface	Score	Group of interventions	Score	Intervention points	Score	Specific actions	Observations
0.323	**A - Solid waste management (SWM) sector interface**	0.333	Access to waste	0.5	Access to waste	1	Legal recognition of the right of pickers to collect waste, sell the materials separated and keep the income	The national law 26.916 of Minimal Budgets to Domestic Waste Management of 2002, in its Article 25 c) determines that the Authority of application of the law "must promote the integration of informal waste collection systems". In addition to the national law 26.916 (see row #1), the Buenos Aires province law 13.592 from 2010 establishes the basic features of the Integrated Waste Management Policy of the province and states in its 3rd article: in point 3), the consideration of waste as resources; in point 6) the principle of SW valorization, and; in point 10) "the economic exploitation of waste, aiming at the the generation of employment in optimal health conditions as a relevant objective, paying special attention to the situation of informal garbage workers"
						0.5	Waste pickers to have controlled access to waste at collection points	The local municipality offered the managing of the second Clean Point (see main text) to the cooperative
						0	Waste pickers to have controlled access to waste at transfer stations, disposal sites or other waste facilities	Waste pickers enter to the landfill but without any agreement. Working conditions are precarious.
				0.166 66667	Role in formal SWM system	0	Inclusion into/ integration with formal SWM sector collection	Waste pickers are not considered as possible formal waste collectors
						0.5	Inclusion into/integration with formal SWM sector transport	The local municipality offered the managing of the second Clean Point (see main text) to the cooperative
						0	Official role in providing recycling within formal SWM system	Waste pickers are still considered as a marginal actor of the recycling system. Non-profit organizations working with the Municipality have much more visibility and receive all collected materials of the Central Clean Point
		0.375	Recognising role of informal sector in SWM	0.25	Socio-political context towards informal sector	0	Institutionalising policies regarding IRS (so that they become robust to political shifts)	Policies regarding IRS are inexistent
						0.5	Documenting the role and advertising benefits provided by IRS within the wider SWM system (acknowledgment of their role and contribution)	Our first project with waste pickers started. It main objective was to make visible the important role of the IRS for the SWM system
				0.5	Promote inclusivity	0.5	Involve all stakeholders in SWM planning	In the context of our first project we organized a planning workshop with non-profit organizations, waste pickers, and the Municipality. However the Municipality miss the workshop. Morever, in 2015 the municipal government announced a plan for installing a non source-separated waste recovering facility. Although this decision was taken completely in isolation, it was never implemented. At the end of this period, they will finally offer to the cooperative the managing of the second Clean Point (see main text)
						0.5	Institutionalise inclusivity of informal sector	The launching of the Mesa GIRSU (see main text), which incorporated the IRS as a core member, give them an institutionalized platform through which they could hold their demands

		0.333	Protecting public health and environment	0.333 33333	Protecting public health and environment	0	Control sorting in the street and ensure that residues after sorting are disposed of properly	Waste pickers still work in isolation, there is no rights nor rules for them
						0	Regulate handling of hazardous wastes	Waste pickers still work in isolation, there is no rights nor rules for them
						1	Promote the collection and disposal of waste from marginalized/low-income areas	The collection of SWM has a 100% coverage
		0.25	Strengthenin g interfaces	0	Improving formal SWM/informal interface	0	Smoothing take over from households or from waste collectors to the IS	Waste pickers still work in isolation, most of them without any contact with landfill authorities or with households
						0	Easing take over from IS to municipalities or private contractors for secondary transport and final disposal	SWM collection is municipal and final disposal is carried out by a private entreprise. There is no contact between waste pickers and these actors
				0.5	National policies improving formal state/informal interface	1	National policies/legislation to promote recycling (considering IRS potential contribution)	The national law 26.916 of Minimal Budgets to Domestic Waste Management of 2002, in its Article 25 c) determines that the Authority of application of the law "must promote the integration of informal waste collection systems"
						0	National strategies for the inclusion of IRS within SWM	There is no national strategy for inclusion of waste pickers. Progress in this aspect runs on behalf the local governments

0.058	**B - Materials and value chain interface**	0	Improving quality of materials for recycling at their source	0	Improving quality of the source materials/ reducing crosscontami nation	0	Source segregation	There is no segregation at the source
						0	Contracts with waste generators	Waste pickers don't work collectively
		0.175	Adding value to the secondary raw materials/pr oducts sold	0.25	Increasing quantity available for sale	0	Use of larger containers/bags by IRS collectors	Waste pickers work in isolation, there is no systematic collection system
						1	Use of wheeled containers by IRS collectors	Most of waste pickers use wheeled containers
						0	Make storage space available	Waste pickers work in isolation, they don't have conditioned separation sites
						0	Expanding the range of materials recycled	Materials recycled by waste pickers are those accepted by local middlemen. There is no intervention of the local government
				0.1	Reprocessing	0.5	Segregating collected materials into distinct categories	Some waste pickers classify their waste at home, others not. Plastics are not commercialized. They don't have the knowledge to dissasemble a computer
						0	Washing/ removing contraries and contaminants	Waste pickers don't have acces to cleaning facilities. Moreover, plastics are not commercialized
						0	Densification (to decrease transport costs and increase density)	Waste pickers don't have acces to waste processing machines
						0	Processing to intermediate product	Waste pickers don't have acces to waste processing machines
						0	Manufacturing final products	Waste pickers don't have acces to waste processing machines

		0	Improving linkages along value chain	0	Improving linkages along value chain	0	Strengthening relation between IRS and recycling industries	Waste pickers don't have direct contact with industries. There is no mechanisms for dialogue with industries or private companies
						0	Contracts with specific middlemen/ recycling industry	Sales to middlemen are made without any formal agreement
						0	Bypassing middlemen	Waste pickers don't have direct contact with industries
						0	Organising middlemen	There is no intervention of the local government

0	**C - Social aspects and interfaces with society**	0	Facilitating recognition and acceptance of the IS	0	Promoting legal recognition	0	Issuing of birth certificates and other legal documents	Waste pickers still work in isolation, there is no rights nor rules for them
						0	Rights and duties: right to vote, land property rights, duty to pay taxes, etc.	Waste pickers still work in isolation, there is no rights nor rules for them
						0	'Light' regulations	There is no national strategy for inclusion of waste pickers. Progress in this aspect runs on behalf the local governments. The existence of waste pickers in Tandil is denied by local authorities
						0	Recognising wastepicking as a profession	There is no recognition of wastepicking as a profession
				0	Facilitating recognition and acceptance	0	Issuing of identity cards	Waste pickers are not provided with identity cards
						0	Provision of uniforms	Waste pickers are not provided with uniforms
				0	Engaging the public in the intervention	0	Through awareness raising campaigns	Public campaigns concern recycling project related to non-profit organizations and that don't consider waste pickers
						0	Through involvement in planning the intervention	SWM planning is carried by the local governement in isolation
						0	Through promoting source separation	There is no segregation at the source
		0	Work towards children, education, and gender equality and inclusivity	0	Facilitating child education	0	Work to eliminate child labour	There is no national strategy for erradicating child labour in the IRS. Progress in this aspect runs on behalf the local governments. The existence of waste pickers in Tandil is denied by local authorities
						0	Incentives to attend school	There is no national strategy for school attending of members of the IRS. Progress in this aspect runs on behalf the local governments. The existence of waste pickers in Tandil is denied by local authorities
						0	Providing schools for waste pickers' children	There is no national strategy for child school attending of members of the IRS. Progress in this aspect runs on behalf the local governments. The existence of waste pickers in Tandil is denied by local authorities
				0	Promoting gender equality/inclusivity	0	Involve women in planning and delivering specific interventions aimed at women	SWM planning is carried by the local governement in isolation. Waste pickers work in isolation, there is no rights nor rules for them
						0	Loans accessible to women	There is no accesible loans to women
		0	Occupational health and safety	0	Ensuring health and safety standards at work	0	Safety equipment	Waste pickers are not provided with safety elements
						0	Access to health care	Waste pickers have not access to health care
						0	Ensure hazardous waste sorted separately	Waste pickers work still in isolation, there is no rights nor rules for them

0.382	O - Enabling actions - organisation & empowerment	0.75	Organisation of informal sector	0.5	Organisation of waste-pickers	0.5	Encourage organisation into groups, e.g. cooperatives, associations, CBOs, MSEs	A group of former members of a local NGO encouraged some waste pickers to organize a cooperative. The local University is also helping the IRS in this process. At the end of this period the legal constitution of the cooperative is not achieved but well advanced. However, the social structure of the cooperative collapsed
				0.5	NGO participation	1	NGO participation— helping the IRS to organise and help themselves	The local environmental NGO is still in contact with waste pickers and promotes face authorities their work
				1	Promote networks on national level	1	Organising national forums and meetings	At the national level, organization of waste pickers is in an advanced stage. From 2012 they have the Argentinean Federation of Waste Pickers and from 2011 the MTE is part of the Confederation of Workers of the Popular Economy (see main article)
						1	Creating a national network of waste pickers	From 2012 they have the Argentinean Federation of Waste Pickers
		0.333	Financial viability	0.333 33333	Financial viability	0	Access to capital for the IRS	The MTE managed to have access to capital to help cooperatives in formation stage but this help is not available for waste pickers of Tandil
						0	Reduce vulnerability to market shifts on prices of materials	Waste pickers work in isolation, there is no rights nor rules for them. There is no intervention of the local government
						1	Dependent on market revenues rather than governmental/ NGOs/project-related subsidies	Waste pickers are completly depending on market revenues
		0.0625	Capacity building	0.125	Capacity-building and development	0.5	Training courses	Waste pickers received a first integrated waste management course from the local university
						0	Literacy courses	Waste pickers don't have access to literacy courses
						0	Involvement in intervention steering committee	Waste pickers don't have access to technical instruction
						0	Understanding buyer's requirements (secondary raw material specifications to be met)	Waste pickers don't have access to technical instruction
				0	Data collection and documentation	0	Record keeping of workforce, tonnes collected, costs and earnings	Waste pickers don't keep records about tonnes collected, costs, etc.

Summary	
Solid waste managemet interface	0.323
Materials and value chain interface	0.058
Social interface	0
Organisation & empowerment	0.382

2017-2018

Score	Interface	Score	Group of interventions	Score	Intervention points	Score	Specific actions	Observations
0.563	A - Solid waste managemet (SWM) sector interface	0.5	Access to waste	0.5	Access to waste	1	Legal recognition of the right of pickers to collect waste, sell the materials separated and keep the income	The national law 26.916 of Minimal Budgets to Domestic Waste Management of 2002, in its Article 25 c) determines that the Authority of application of the law "must promote the integration of informal waste collection systems". In addition to the national law 26.916, the Buenos Aires province law 13.592 from 2010 establishes the basic features of the Integrated Waste Management Policy of the province and states in its 3rd article: in point 3), the consideration of waste as resources; in point 6) the principle of SW valorization, and; in point 10) "the economic exploitation of waste, aiming at the the generation of employment in optimal health conditions as a relevant objective, paying special attention to the situation of informal garbage workers"
						0.5	Waste pickers to have controlled access to waste at collection points	The cooperative started to receive junk from the Clean Point (see main text)
						0	Waste pickers to have controlled access to waste at transfer stations, disposal sites or other waste facilities	Waste pickers enter to the landfill but without any agreement. Working conditions are precarious.
				0.5	Role in formal SWM system	0	Inclusion into/ integration with formal SWM sector collection	Waste pickers are not considered as possible formal waste collectors
						0.5	Inclusion into/integration with formal SWM sector transport	The local municipality offered the managing of the second Clean Point (see main text) to the cooperative
						1	Official role in providing recycling within formal SWM system	Waste pickers are now considered as main actor of the recycling system
		0.625	Recognising role of informal sector in SWM	0.75	Socio-political context towards informal sector	0.5	Institutionalising policies regarding IRS (so that they become robust to political shifts)	Through Mesa GIRSU, an ordinance project was proposed to the municipality (Mesa GIRSU 2018), and is now under evaluation. It aimed to regulate large waste generators and put the IRS as first destination for recyclables.
						1	Documenting the role and advertising benefits provided by IRS within the wider SWM system (acknowledgment of their role and contribution)	Our second project with waste pickers started. We made a Material Flow Analysis of waste flows and calculate the first recycling indicators, showing that the IRS was responsible of 80-90% of the local recycling
				0.5	Promote inclusivity	0.5	Involve all stakeholders in SWM planning	Mesa GIRSU organized different ordinance projects taking into account the IRS. However, as the municipality is not participating in Mesa GIRSU, the projects are being studied by authorities from several months
						0.5	Institutionalise inclusivity of informal sector	The launching of the Mesa GIRSU (see main text), which incorporated the IRS as a core member, give them an institutionalized platform through which they could hold their demands
		0.5	Protecting public health	0.5	Protecting public health	0.5	Control sorting in the street and ensure that residues after sorting are disposed of properly	One of the main objectives of the cooperative is to stablish a good relation with society. Members of the cooperative are asked to maintain clean the street after collecting materials and to pick up all separated material even

			and environment		and environment			if it includes some materials that have not a market destination. Importantly, not all waste pickers are included in the cooperative
						0	Regulate handling of hazardous wastes	There is no regulation for the handling of hazardous waste
						1	Promote the collection and disposal of waste from marginalized/low-income areas	The collection of SWM has a 100% coverage
		0.625	Strengthening interfaces	0.25	Improving formal SWM/informal interface	0	Smoothing take over from households or from waste collectors to the IS	There is no source segregation, therefore, there is no smoothing take over from households
						0.5	Easing take over from IS to municipalities or private contractors for secondary transport and final disposal	The cooperative and the Municipality have frequent but rough contact
				1	National policies improving formal state/informal interface	1	National policies/legislation to promote recycling (considering IRS potential contribution)	The national law 26.916 of Minimal Budgets to Domestic Waste Management of 2002, in its Article 25 c) determines that the Authority of application of the law "must promote the integration of informal waste collection systems"
						1	National strategies for the inclusion of IRS within SWM	The Social Emergency Law (see main text) was converted, in the facts, in a national strategy allowing IRS integration
0.325	**B - Materials and value chain interface**	0	Improving quality of materials for recycling at their source	0	Improving quality of the source materials/ reducing crosscontamination	0	Source segregation	There is no segregation at the source
						0	Contracts with waste generators	Waste pickers don't have individual contracts with large waste generators
		0.6	Adding value to the secondary raw materials/products sold	1	Increasing quantity available for sale	1	Use of larger containers/bags by IRS collectors	The organisation of the work in the cooperative served to diffuse best practice among their members, including the use of larger bags. Moreover, through a university extension project (see main text) we bough several big-bags for IRS use
						1	Use of wheeled containers by IRS collectors	Most of waste pickers use wheeled containers
						1	Make storage space available	With the rent subsidy of the Municipality, the cooperative accesed to a storage space
						1	Expanding the range of materials recycled	Through the MTE Buenos Aires, the number of materials that is possible to sell increased greatly
				0.2	Reprocessing	1	Segregating collected materials into distinct categories	Classifying of waste has been improved. Plastics are commercialized. The MTE give insights about best practice in waste segregation
						0	Washing/ removing contraries and contaminants	Waste pickers don't have acces to cleaning facilities.
						0	Densification (to decrease transport costs and increase density)	Waste pickers don't have acces to waste processing machines
						0	Processing to intermediate product	Waste pickers don't have acces to waste processing machines

						0	Manufacturing final products	Waste pickers don't have acces to waste processing machines
		0.375	Improving linkages along value chain	0.375	Improving linkages along value chain	0.5	Strengthening relation between IRS and recycling industries	Through the MTE Buenos Aires, the cooperative is in contact with industries
						0.5	Contracts with specific middlemen/ recycling industry	Even if there is no contracts with industries or middlemen, as waste pickers become better organised, contacts with local industries are more frequent and their consider the possibility of following this way
						0.5	Bypassing middlemen	Waste pickers storage some materials in the shed, but are still unable to bypass middlemen. However, this is clearly an objective in consideration
						0	Organising middlemen	There is no intervention of the local government

0.333333333	**C - Social aspects and interfaces with society**	0.333	Facilitating recognition and acceptance of the IS	0.5	Promoting legal recognition	0.5	Issuing of birth certificates and other legal documents	MTE support includes help with legal issues. Local MTE people started by plannifying a waste pickers census.
						0.5	Rights and duties: right to vote, land property rights, duty to pay taxes, etc.	When working in a cooperative or independently, waste pickers, as other independent workers, can demand the "Monotributo Social". This is a new tributary category, designed for workers of the social economy. It allows ths workers to be part of the formal economy, having access to health care and contributory social security. Even if this instrument is available from 2004, without the assitance of the MTE, most waste pickers continue to work without this benefits
						0	'Light' regulations	There is no national strategy for inclusion of waste pickers. Progress in this aspect runs on behalf the local governments.
						1	Recognising wastepicking as a profession	The Resolution 32/16 of the Ministry of Labour and the Social Emergency Law recognize waste picking as a profession of the popular economy
				0	Facilitating recognition and acceptance	0	Issuing of identity cards	Waste pickers are not provided with identity cards
						0	Provision of uniforms	Waste pickers are not provided with uniforms
				0.5	Engaging the public in the intervention	0.5	Through awareness raising campaigns	Through the Promotoras Ambientales program (see main text) public is awarned about inclusive recycling. However, municipal awareness campaigns are still focused on Clean Points, which connects to other associations
						0.5	Through involvement in planning the intervention	Promotoras Ambientales is a program performed by waste picker women. However, municipal awareness campaigns are still focused on Clean Points, which connects to other associations
						0.5	Through promoting source separation	Through the Promotoras Ambientales program (see main text) households and schools are incited to separate waste at source and bring it to the cooperative shed. However, municipal awareness campaigns are still focused on Clean Points, which connects to other associations
		0.5	Work towards	0.5		0.5	Work to eliminate child labour	MTE support includes help with child labpur issues. Local MTE people started by plannifying a waste pickers census to identify child labour cases

			children, education, and gender equality and inclusivity		Facilitating child education	0.5	Incentives to attend school	MTE support includes help to organize this kind of issues. Local MTE people started by plannifying a waste pickers census to identify people who need attending to school
						0.5	Providing schools for waste pickers' children	MTE support includes help to organize this kind of issues. Local MTE people started by plannifying a waste pickers census to identify cases of waste pickers' children not attending school
				0.5	Promoting gender equality/inclusivity	1	Involve women in planning and delivering specific interventions aimed at women	Promotoras Ambientales is a program performed by waste picker women and completly coordinated by them
						0	Loans accessible to women	There is no accesible loans to women
		0.166	Occupational health and safety	0.166	Ensuring health and safety standards at work	0	Safety equipment	Waste pickers are not provided with safety elements
						0.5	Access to health care	Through the Monotributo Social (see row 37), waste pickers have access to health care. In the period 2017-2018, a great number of waste pickers of Tandil still work in isolation and are not inscribed in this tributary regime
						0	Ensure hazardous waste sorted separately	This issue is still not addressed

0.410	**O - Enabling actions - organisation & empowerment**	1	Organisation of informal sector	1	Organisation of waste-pickers	1	Encourage organisation into groups, e.g. cooperatives, associations, CBOs, MSEs	Through the MTE and the Complementary Social Salary (see main text), in this period the cooperative achieved a new equilibrium
				0.5	NGO participation	1	NGO participation— helping the IRS to organise and help themselves	The local environmental NGO is still in contact with waste pickers and promotes face authorities their work
				1	Promote networks on national level	1	Organising national forums and meetings	At the national level, organization of waste pickers is in an advanced stage. From 2012 they have the Argentinean Federation of Waste Pickers and from 2011 the MTE is part of the Confederation of Workers of the Popular Economy (see main article)
						1	Creating a national network of waste pickers	From 2012 they have the Argentinean Federation of Waste Pickers
		0.166	Financial viability	0.166	Financial viability	0	Access to capital for the IRS	The MTE managed to have access to capital to help cooperatives in formation stage but this help is not available for waste pickers of Tandil
						0	Reduce vulnerability to market shifts on prices of materials	There is no intervention of the local government
						0.5	Dependent on market revenues rather than governmental/ NGOs/project-related subsidies	The municipality finally accepted to give a shed rent subsidy to the cooperative. Thus, at the end of this period the cooperative is partially dependent on this subsidy and not completly market driven
		0.0625	Capacity building	0.125	Capacity-building and development	0.5	Training courses	Waste pickers receive training courses on behalf of the MTE, destinated in this period mostly to Promotoras Ambientales
						0	Literacy courses	Waste pickers don't have access to literacy courses
						0	Involvement in intervention steering committee	Waste pickers don't have access to technical instruction
						0	Understanding buyer's requirements (secondary raw material specifications to be met)	Waste pickers don't have access to technical instruction
				0	Data collection and	0	Record keeping of workforce, tonnes collected, costs and earnings	Waste pickers don't keep records about tonnes collected, costs, etc.

					documentation			

Summary	
Solid waste managemet interface	0.562
Materials and value chain interface	0.325
Social interface	0.333
Organisation & empowerment	0.410

2019

Score	Interface	Score	Group of interventions	Score	Intervention points	Score	Specific actions	Observations
0.583	**A - Solid waste managemet (SWM) sector interface**	0.583	Access to waste	0.666	Access to waste	1	Legal recognition of the right of pickers to collect waste, sell the materials separated and keep the income	The national law 26.916 of Minimal Budgets to Domestic Waste Management of 2002, in its Article 25 c) determines that the Authority of application of the law "must promote the integration of informal waste collection systems". In addition to the national law 26.916, the Buenos Aires province law 13.592 from 2010 establishes the basic features of the Integrated Waste Management Policy of the province and states in its 3rd article: in point 3), the consideration of waste as resources; in point 6) the principle of SW valorization, and; in point 10) "the economic exploitation of waste, aiming at the the generation of employment in optimal health conditions as a relevant objective, paying special attention to the situation of informal garbage workers"
						0.5	Waste pickers to have controlled access to waste at collection points	The cooperative started to receive junk from the Clean Point (see main text)
						0.5	Waste pickers to have controlled access to waste at transfer stations, disposal sites or other waste facilities	An agreement has been signed between waste pickers and the landfill managing entreprise. Determinated time-frames for waste pickers entry have been defined. Working conditions are stiil precarious
				0.5	Role in formal SWM system	0	Inclusion into/ integration with formal SWM sector collection	Waste pickers are not considered as possible formal waste collectors
						0.5	Inclusion into/integration with formal SWM sector transport	The local municipality offered the managing of the second Clean Point (see main text) to the cooperative
						1	Official role in providing recycling within formal SWM system	Waste pickers are now considered as main actor of the recycling system
		0.625	Recognising role of informal sector in SWM	0.75	Socio-political context towards informal sector	0.5	Institutionalising policies regarding IRS (so that they become robust to political shifts)	Through Mesa GIRSU, an ordinance project was proposed to the municipality (Mesa GIRSU 2018), and is now under evaluation. It aimed to regulate large waste generators and put the IRS as first destination for recyclables.
						1	Documenting the role and advertising benefits provided by IRS within the wider SWM system (acknowledgment of their role and contribution)	Our second project with waste pickers started. We made a Material Flow Analysis of waste flows and calculate the first recycling indicators, showing that the IRS was responsible of 80-90% of the local recycling
				0.5	Promote inclusivity	0.5	Involve all stakeholders in SWM planning	Mesa GIRSU organized different ordinance projects taking into account the IRS. However, as the municipality is not participating in Mesa GIRSU, the projects are being studied by authorities from several months
						0.5	Institutionalise inclusivity of informal sector	The launching of the Mesa GIRSU (see main text), which incorporated the IRS as a core member, give them an institutionalized platform through which they could hold their demands
		0.5	Protecting public health	0.5	Protecting public health	0.5	Control sorting in the street and ensure that residues after sorting are disposed of properly	One of the main objectives of the cooperative is to stablish a good relation with society. Members of the cooperative are asked to maintain clean the street after collecting materials and to pick up all separated material even

			and environment		and environment			if it includes some materials that have not a market destination. Importantly, not all waste pickers are included in the cooperative
						0	Regulate handling of hazardous wastes	There is no regulation for the handling of hazardous waste
						1	Promote the collection and disposal of waste from marginalized/low-income areas	The collection of SWM has a 100% coverage
		0.625	Strengthening interfaces	0.25	Improving formal SWM/informal interface	0	Smoothing take over from households or from waste collectors to the IS	There is no source segregation, therefore, there is no smoothing take over from households
						0.5	Easing take over from IS to municipalities or private contractors for secondary transport and final disposal	The cooperative and the Municipality have frequent but rough contact
				1	National policies improving formal state/informal interface	1	National policies/legislation to promote recycling (considering IRS potential contribution)	The national law 26.916 of Minimal Budgets to Domestic Waste Management of 2002, in its Article 25 c) determines that the Authority of application of the law "must promote the integration of informal waste collection systems"
						1	National strategies for the inclusion of IRS within SWM	The Social Emergency Law (see main text) was converted, in the facts, in a national strategy allowing IRS integration

0.525	**B - Materials and value chain interface**	0.25	Improving quality of materials for recycling at their source	0.25	Improving quality of the source materials/ reducing crosscontamination	0.5	Source segregation	Citizens of some neighborhoods, auto-organize recyclable waste separation journeys. One faculty of the University started, with Promotoras, a source-segration program in which all materials are destinated to the cooperative
						0	Contracts with waste generators	Waste pickers don't have individual contracts with large waste generators
		0.7	Adding value to the secondary raw materials/products sold	1	Increasing quantity available for sale	1	Use of larger containers/bags by IRS collectors	The organisation of the work in the cooperative served to diffuse best practice among their members, including the use of larger bags. Moreover, through a university extension project (see main text) we bough several big-bags for IRS use
						1	Use of wheeled containers by IRS collectors	Most of waste pickers use wheeled containers
						1	Make storage space available	With the rent subsidy of the Municipality, the cooperative accesed to a storage space
						1	Expanding the range of materials recycled	Through the MTE Buenos Aires, the number of materials that is possible to sell increased greatly
				0.4	Reprocessing	1	Segregating collected materials into distinct categories	Classifying of waste has been improved. Plastics are commercialized. The MTE give insights about best practice in waste segregation
						0	Washing/ removing contraries and contaminants	Waste pickers don't have acces to cleaning facilities.
						1	Densification (to decrease transport costs and increase density)	The cooperative installed a press machine
						0	Processing to intermediate product	Waste pickers don't have acces to advanced waste processing machines

						0	Manufacturing final products	Waste pickers don't have acces to advanced waste processing machines
		0.625	Improving linkages along value chain	0.625	Improving linkages along value chain	0.5	Strengthening relation between IRS and recycling industries	Through the MTE Buenos Aires, the cooperative is in contact with industries
						1	Contracts with specific middlemen/ recycling industry	The cooperative have now power of negotiation with middlemen. Some materials, like junk, are locally sell; in this cases, specific agreements have been agreed.
						1	Bypassing middlemen	Waste pickers storage can now bypass middlemen for most of the materias, which are sent to Buenos Aires
						0	Organising middlemen	There is no intervention of the local government

0.444	**C - Social aspects and interfaces with society**	0.5	Facilitating recognition and acceptance of the IS	0.5	Promoting legal recognition	0.5	Issuing of birth certificates and other legal documents	MTE support includes help with legal issues.The waste pickers' census is being performed.
						0.5	Rights and duties: right to vote, land property rights, duty to pay taxes, etc.	When working in a cooperative or independently, waste pickers, as other independent workers, can demand the "Monotributo Social". This is a relatevly new tributary category, designed for workers of the social economy. It allows this workers to be part of the formal economy, having access to health care and contributory social security. Even if this instrument is available from 2004, without the assitance of the MTE, most waste pickers continue to work without this benefits
						0	'Light' regulations	There is no national strategy for inclusion of waste pickers. Progress in this aspect runs on behalf the local governments.
						1	Recognising wastepicking as a profession	The Resolution 32/16 of the Ministry of Labour and the Social Emergency Law recognize waste picking as a profession of the popular economy
				0.5	Facilitating recognition and acceptance	0.5	Issuing of identity cards	The cooperative is analysing how to provide identity cards to its members
						0.5	Provision of uniforms	Through MTE, uniforms, security accesories and other stuff have been solicitated to the Social Development Ministry
				0.5	Engaging the public in the intervention	0.5	Through awareness raising campaigns	Through the Promotoras Ambientales program (see main text) public is awarned about inclusive recycling. However, municipal awareness campaigns are still focused on Clean Points, which connects to other associations
						0.5	Through involvement in planning the intervention	Promotoras Ambientales is a program performed by waste picker women. However, municipal awareness campaigns are still focused on Clean Points, which connects to other associations
						0.5	Through promoting source separation	Through the Promotoras Ambientales program (see main text) households and schools are incited to separate waste at source and bring it to the cooperative shed. However, municipal awareness campaigns are still focused on Clean Points, which connects to other associations
		0.5	Work towards	0.5		0.5	Work to eliminate child labour	MTE support includes help with child labpur issues. Local MTE people started by plannifying a waste pickers census to identify child labour cases

			children, education, and gender equality and inclusivity		Facilitating child education	0.5	Incentives to attend school	MTE support includes help to organize this kind of issues. Local MTE people started by plannifying a waste pickers census to identify people who need attending to school
						0.5	Providing schools for waste pickers' children	MTE support includes help to organize this kind of issues. Local MTE people started by plannifying a waste pickers census to identify cases of waste pickers' children not attending school
				0.5	Promoting gender equality/inclusivity	1	Involve women in planning and delivering specific interventions aimed at women	Promotoras Ambientales is a program performed by waste picker women and completly coordinated by them
						0	Loans accessible to women	There is no accesible loans to women
		0.333	Occupational health and safety	0.333	Ensuring health and safety standards at work	0.5	Safety equipment	Through MTE, uniforms, security accesories and other stuff have been solicitated to the Social Development Ministry
						0.5	Access to health care	Through the Monotributo Social (see row 37), waste pickers have access to health care. In the period 2017-2018, some waste pickers of Tandil still work in isolation and are not inscribed in this tributary regime
						0	Ensure hazardous waste sorted separately	This issue is still not addressed

0.674	**O - Enabling actions - organisation & empowerment**	1	Organisation of informal sector	1	Organisation of waste-pickers	1	Encourage organisation into groups, e.g. cooperatives, associations, CBOs, MSEs	Through the MTE and the Complementary Social Salary (see main text), in this period the cooperative achieved a new equilibrium
				0.5	NGO participation	1	NGO participation— helping the IRS to organise and help themselves	The local environmental NGO is still in contact with waste pickers and promotes face authorities their work
				1	Promote networks on national level	1	Organising national forums and meetings	At the national level, organization of waste pickers is in an advanced stage. From 2012 they have the Argentinean Federation of Waste Pickers and from 2011 the MTE is part of the Confederation of Workers of the Popular Economy (see main article)
						1	Creating a national network of waste pickers	From 2012 they have the Argentinean Federation of Waste Pickers
		0.333	Financial viability	0.333	Financial viability	0.5	Access to capital for the IRS	The MTE managed to have access to capital to help cooperatives in formation stage. As the Tandil's cooperative made important progress in its organization, they are now considered as a possible destination of these benefits
						0	Reduce vulnerability to market shifts on prices of materials	There is no intervention of the local government
						0.5	Dependent on market revenues rather than governmental/ NGOs/project-related subsidies	The municipality finally accepted to give a shed rent subsidy to the cooperative. Thus, the cooperative is partially dependent on this subsidy and not completly market driven
		0.6875	Capacity building	0.375	Capacity-building and development	0.5	Training courses	Waste pickers receive training courses on behalf of the MTE
						0	Literacy courses	Waste pickers don't have access to literacy courses
						0	Involvement in intervention steering committee	Waste pickers don't have access to technical instruction

						1	Understanding buyer's requirements (secondary raw material specifications to be met)	Cooperative members have a direct contact with MTE Buenos Aires people, who give them instructions related to materials specifications to be met
				1	Data collection and documentation	1	Record keeping of workforce, tonnes collected, costs and earnings	Waste pickers started to keep records about tonnes collected, costs, etc.

Summary	
Solid waste managemet interface	0.583
Materials and value chain interface	0.525
Social interface	0.444
Organisation & empowerment	0.674

PART III

§ Final remarks

12

Conclusion

This section summarizes the insights gained during the development of the thesis in terms of approaching WM as a PCP. In the next section (12.1), we will first sketch an integration of the different conceptual frameworks we mobilized in Part I of the thesis. This integration is organized around the two main challenges we identified during our work: the democratic challenge and the knowledge challenge. Then, we will advance some preliminary reflections about the general dynamic we need to put in place when addressing a PCP. In section 12.2, we will re-analyse our case study, the waste management of Tandil, under this new perspective.

To conclude the thesis, in section 12.3 we will analyse the future research and action perspectives.

12.1 Integrating different conceptual approaches to deal with the needed regime destabilization and its two main challenges: democratic and knowledge challenges

In this thesis we approached WM of Tandil city as a Persistent Complex Problem (defined in Ch. 3). All along our work, we identified and used specific tools such as MFA, waste characterizations or the InteRa framework, which were adequate to address WM as a PCP in Tandil.

Clearly, suitable methodologies and tools are needed to address a specific PCP. These methodologies must be adapted to the PCP inner characteristics, such as the spatial and temporal frames it mobilises, its associated technological complexity, and what it puts at stake, among others, as well as the economic, political, cultural, and many other contexts in which it develops.

This does not mean, however, that PCPs do not share common features nor that general patterns or dynamics cannot be identified. In Ch. 3 we presented two models or tools that have been widely used to conceptualize and address PCPs: the Multi-Level

Perspective (MLP) and the S curve of transitions and its phases (Multi-Phase Perspective, MPP).

MLP is useful to characterize the PCP, while the MPP is useful to describe the general trajectory of the desired transition from one state of the PCP to another. Alone however, they do not offer any insights about the actions needed to move along the S curve. Thus, the Transition Management cycle is aimed at providing these insights. It proposes, among other actions, the creation of a "transition arena" and the performance of "transition experiments" (see Ch. 3).

Yet, in our opinion and on the basis of the experience we gained during the thesis, the TM model, as it is presented, is unable to reflect the main challenges associated with PCPs: the democratic and the knowledge challenges[71].

Using the MLP model, we can say that addressing a PCP implies to destabilize its socio-technical regime. This regime was defined as "a dominant and stable configuration in a societal system (...) [that] emerged out of historical transitions and developed path-dependently through processes of optimization and incremental innovation" (Loorbach et al., 2017, p. 605). As we mentioned in Ch. 3, changing the regime is difficult because it has an (undesirable) resilience: it evolved by accumulating lock-in situations which make its configuration stable.

As PCP involves, by definition, the way societies organize and perform (frequently at the city level) basic questions such as transport, energy provision, water management, and waste management, among others, the development (past, present and future) of a PCP is part of the political realm and should be part of a democratic process.

Thus, the destabilization of the PCP regime mentioned above, should also be part of a democratic process. Moreover, as we mentioned in Ch. 3, solutions proposed to PCPs will always be controversial, and therefore subject to public debates in open spaces as hybrid forums. Also, in many cases, PCPs are not perceived as problems by the main actors (including government authorities). In these cases, we can argue that a hybrid forum can be a prerequisite to install the PCP as a societal concern.

Figure 54 and Figure 53 present a complementing and preliminary model or framework which tries to summarize, on the basis of our working experience during

[71] The knowledge challenge was addressed in Ch. 3.

the thesis, first, the main challenges associated with regime destabilization, and second, the dynamic we need to put in place when we want to walk through the phases of the transition.

Figure 53 tries to reflect the tension between the regime undesirable resilience (Dornelles et al., 2020) and its destabilization which is necessary to trigger and sustain a transition process. The democratic and the knowledge challenges arise from the encounter of these two opposed interests.

Figure 53: The two main challenges to address when trying to destabilize a resilient regime in the context of a sustainability transition. Source: the author

We selected three main issues related to each concept, even if many others can be included to describe them. Other challenges result from these contrasting intentions, as well. However, the purpose of our development here is not to construct a full new model to guide transitions in PCPs, but to complement existing approaches and to set the bases for further development.

Our focus on transdisciplinarity in Ch. 3 and the inclusion of technical democracy, boundary organizations and TM concepts in section *3.5 Selected complementary approaches, concepts and tools*, was part of an early identification of these challenges. Here, we integrate all these concepts under a new perspective.

Regarding Figure 53, transdisciplinary research (TdR) is an adequate framework to deal with the knowledge challenge, as explained in Ch. 3. Boundary work and boundary organizations can be useful to deal with both challenges. Participatory democracy is, of course, a field intended to enhance public participation, dealing with power issues, which is part of the democratic challenge. Finally, a hybrid forum is a key element to destabilize the regime, while controversy analysis and management are useful to deal with the questions, worries, and reactions to the negative (and positive) impacts of the different new regime alternatives explored.

Figure 54 complements the previous analysis. It summarizes the main actions which need to be permanently performed when addressing a PCP with the aim of triggering and driving a transition through its phases.

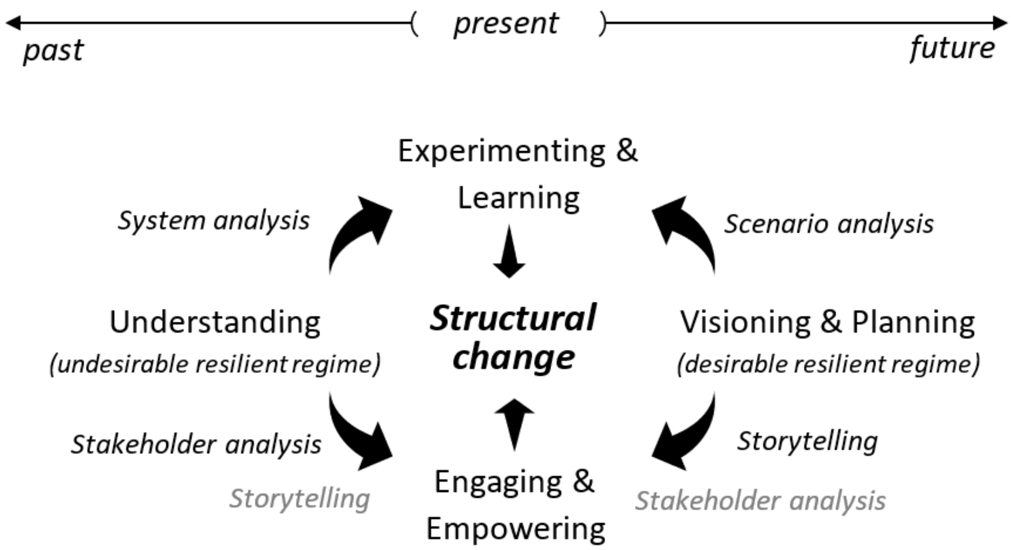


Figure 54: A general model of basic PCP transition dynamic. Source: the author

This second part of the framework attempts to acknowledge the importance of, first, understanding the current (undesirable) state of the system through the analysis of its evolution in the past until the present and, second, of visioning a desirable future and planning how to get there. Both processes feed, through different tools, four key permanent actions: experimenting and learning, engaging and empowering. These actions, in turn, should be devoted to achieving structural change (or radical change; Fischer-Kowalski and Rotmans, 2009). What is understood as structural change will depend of the type of PCP and on the context in which it is addressed.

12.2 Re-analysis of Tandil case

12.2.1 A mixed-waste regime

In the MLP, the regime is defined as the "dominant practices, rules and technologies (and ensuing logic of appropriateness) that pertain in the domain, giving it stability and guiding decision-making" (Loorbach, 2004, p. 4).

In the case of Tandil, the regime is defined by means of the mixed-waste collection without treatment. The origin of the regime can be tracked back to the incorporation of the first trucks to collect waste[72]. Thereafter, the system followed nothing more than a path of lineal improvements regarding technology: the trucks were renewed, more trucks were incorporated, a GPS tracking system was installed to all trucks, and the final uncontrolled disposal shifted to controlled dumping. However, the system operation is basically the same. Moreover, the project of the mixed-waste treatment plant did not represent a radical innovation[73], as it would be the case of a source separated collection system.

We can then evaluate the lock-in mechanisms or barriers to change this socio-technical system (Geels et al., 2019). One of the aspects highlighted by municipal officials is the "sunk cost" of compactor trucks. Indeed, when asked about the possibility of implementing a source-separated collection, the Environmental Director Office (Fernández, 2015): stated: "[source-separated collection] implies to change the whole system because you should discard the trucks you have". Also, the Services Director (in charge of the waste collection phase), stated on the local TV that they see containerized collection as an imperative, but "this implies to buy trucks with a lateral loading system and that, at the same time, can wash the containers (...) this is a very important investment" (EcoTV, 2019). At the same time, the current collection system is viewed as a "headlong rush". In the words of the Service Director: "Regarding technology, nothing is enough. Because, for example, we invested in 8 new compactor trucks, but this year [2019] we need to buy two new ones. That is because the city grows in such an uncontrollable way that you find yourself in a situation where everything you acquire is not enough" (ibidem).

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[72] We could not find information about the beginning of the truck-system collection.

[73] Transition governance, on the contrary, implies "to focus on radical and transformative technological and social innovation in earlier stages of transitions as well as strategies focused on dealing with regime destabilization and institutionalization of emerging transitions" (Loorbach et al., 2017, p. 613).

The municipal collection personnel are another important factor. They have a significant influence on the decision-making because, if they go on strike, waste accumulates in the streets. Avoiding trouble with them, therefore, is a reason for not implementing changes that they could perceive as unfavourable. This can be illustrated by Leticia Saligari's (responsible of the Children Hospital Foundation PET recovery program) (Saligari, 2017) statement: "We presented [to the local government] an ordinance draft (…) [proposing] an alternate collection, 3 days for the organic and 2 for the inorganic. No, they told us they did not want a problem with the Labour Union".

Another aspect we could mention is the absence of a local waste ordinance and the (normalised) non fulfilment of the legal framework. At the local level, the current system is only inscribed in people's habits and customs. Moreover, there is no reference site to consult how and when people should dispose waste for collection. In the second case, the Environment Office Director considered that the Law does not actually request the waste final disposal reduction objectives inscribed in its text because the text also states that the Province should provide funds to the municipalities, which has never happened (Fernández, 2015). The reasoning is: the Province is not meeting its own requirements inscribed in the Law; therefore, the Law's requirements regarding municipalities are not applicable.

12.2.2 Several niches innovations

The mixed-waste regime, however, was challenged by several niche innovations. As we mentioned in Ch. 5, the first large-scale recycling waste recovery program was launched in 2009, led by a civil society association; eventually, other similar programs followed.

The PET recovery program, implemented by the local Children Hospital Foundation, besides having the approval of public opinion, was conducted by people coming from very influential local families. They had direct contact with the city Mayor and asked for a greater involvement of the Municipality with recycling. Some years later, in 2014, the Municipality announced the launch of the municipal Clean Points program (see Ch. 9 and 10): a set of facilities where citizens could take their disposable recycling materials. Importantly, even if this strategy was a change affecting the regime because it was anchored in the municipal structure, it did not confront directly with the mixed-waste regime.

In 2013, also, the environmental NGO *Punto Verde* was formed. It immediately became involved with the waste issue and in 2014 it presented an ordinance project for the implementation of a source-separated waste collection system. Moreover, in 2014, they contacted waste pickers to launch a program of recycling waste recovery in schools. Even when this program was cancelled later, this interaction had positive outcomes: it led some members of the NGO who worked at the local university and also at the Federation of Work Cooperatives (FEECOTRA), to propose some waste pickers working on the school's program to be part of a University Extension project proposal at the School level (see Figure 46 in section 8.6). The aim of the project was to improve the organization of waste pickers through the creation of a Cooperative.

The Cooperative was created, and their work is increasing every month (Ch. 10 and 11).

12.2.3 A changing landscape

Finally, we can analyse how the landscape was configured and changed. In Ch. 4 and 5 we presented the waste management legal framework in place for Tandil city. Provincial Law 13.592/06 meant a clear change in the landscape because it introduced concrete objectives regarding the final waste disposal.

On the other hand, the general situation of the waste management in the Province discouraged improvements of the recycling system[74]. In the words of María Condino, ancient city councillor for the official political party: "There is a provincial law that requires Municipalities to begin the recycling work, but we, as the Municipality of Tandil, are one of the 21 out of 134 that have a landfill" (El Eco de Tandil, 2008).

We can also mention the citizens' will to have a source-separated waste collection system. Indeed, a survey made by the city Statistics Office *(Dirección de Estadística*, 2017) found that 86,6% of respondents answered affirmatively to the question *Would you agree with the Municipality collecting source-classified waste separately?*

Finally, a factor that emerged during our work was the enforcement, in 2017, of a Social Emergency Law sanctioned at the national level. It implied the implementation of a "complementary social salary" to all workers of the "popular economy" (PE). This changed the inclusion possibilities of the informal recycling sector. In Ch. 11 we

[74] We have called this the "in the land of the blind, the one-eyed man is king" effect (Villalba, 2017), meaning that compared to a large part of the Province, the actual waste management system (with near-zero recycling) is one of the best.

summarized most actions taken to improve the IRS inclusion and how it impacted in its integration to the formal WM system.

12.2.4 Stimulating the waste management Hybrid Forum to destabilize the regime

Part of the work we made or in which we participated and that is not reflected in the thesis is related to revitalizing the existing hybrid forum about waste management of Tandil. Primarily, it was performed through different actions carried out by or through the Mesa GIRSU (see Ch. 8) and was aimed at interrogating central aspects of the local WM policy, such as what was understood as an integrated and sustainable waste management system, the way WM decisions were taken, and the recognition of the waste pickers, among others.

Figure 55 schematizes the dynamic of this hybrid forum invigoration.

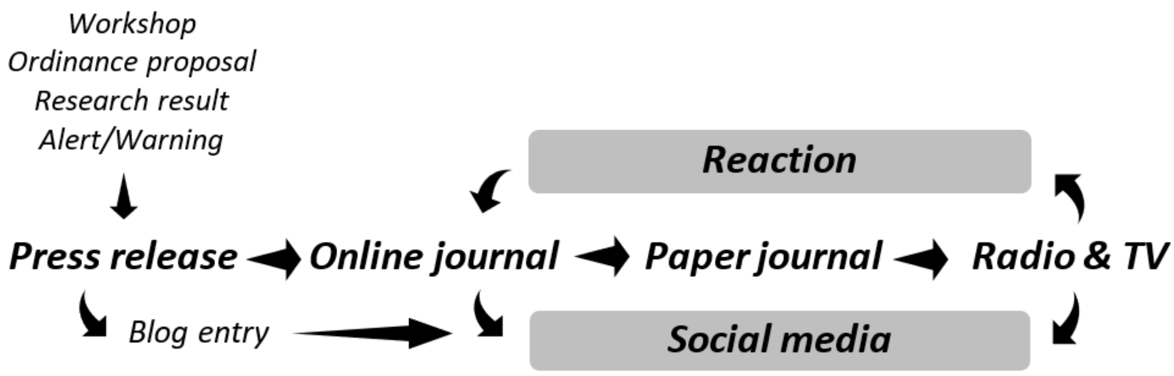

Figure 55: Dynamic of the Hybrid Forum invigoration by the Mesa GIRSU

Part of the hybrid forum work was the creation of a record of the decisions, omissions, proposals, etc., related to the waste management of Tandil. The Blog articles written (www.mesagirsu.org/blog) helped us to build a coherent, consistent, and popularized critique of the current waste management regime.

12.2.5 The knowledge challenge in Tandil

Regarding the challenges identified in the previous section, we consider that our thesis contributes mostly to the knowledge challenge. Our general approach was to combine a local transformation and action-research framework, the Latin American Extension, with other transformational approaches used to solve societal persistent complex problems (Ch. 3 and 7). To achieve this, we worked iteratively, adapting our objectives to several changes that occurred during the thesis. These changes were related to the system structure and functioning (i.e. the opening of the Municipal Clean Points), the actors involved (i.e. the creation of the Mesa GIRSU) and external positive and negative perturbations (i.e. the Complementary Social Salary or the economic crisis).

We addressed the three types of knowledge a transdisciplinary project is based on (Pohl and Hirsch Hadorn, 2007): 1) system knowledge, i.e. knowledge about what it is; 2) target knowledge, i.e. knowledge about what should be, and; 3) transformation knowledge, i.e. knowledge about how to pass from the current situation to the targeted situation. We will shortly recall what we performed regarding these three types of knowledge.

Along with the general characterization of the waste management system, the system knowledge generated was mainly related to the household waste generation and composition and to the importance of the Informal Recycling Sector in the recovery of resources from waste (Ch. 9 and 10). In the first case (Villalba et al., 2020), we worked with other researchers and students to apply a standardized methodology of waste characterization under budget constraints. We stratified households into three socioeconomic status (High, Medium, and Low) using Geographical Information Systems and census data, and performed three one-week sampling campaigns over a year. We obtained the generation rate per category of waste, information that was used in our second article. Our role in this phase was to plan the samplings and the co-organization of the daily work, gather and process data, and analyse results. Since I led the main activities of the study, including the operations planning and coordination, and this work was not other researchers' first priority, the research article was written by me. During the writing process, I identified several specificities related to the high loss of mass during the picking analysis in our results.

In our second article (Ch. 10), we used the information of waste generation in combination with other primary and secondary sources with two main purposes: 1) to calculate indicators related to formal and informal waste recovery; 2) to evaluate how the system worked regarding the drivers of integrated sustainable waste management (ISWM) (Stanisavljevic and Brunner, 2014; UNEP and ISWA, 2015; Wilson et al., 2015). Our results showed that, as in many cities of developing countries (Scheinberg, 2012), informal recovery is higher than formal recovery. Moreover, we identified and estimated quantitatively the amount of waste illegally disposed in open dumps through private skips for the studied year and the inadequacy of current local recovery strategies regarding the legislation of Buenos Aires province.

The target knowledge related to what an adequate waste management framework for Tandil should be was first approached theoretically (Ch. 2). After a general analysis, we stated that waste management is a key element of a circular economy and that, as such, it should be part of coordinated actions at the local, regional and national/international levels (see Figure 19 of Ch. 2). However, even if externally conditioned, waste management at the local level needs a specific framework. In our development, this specific framework was based on the ISWM and included, besides its technical and governance aspects, several transformational aspects as well (see Ch. 8, Figure 51). Our intention with this development was to have an initial discussion proposal to be worked on in the context of a transdisciplinary arena, which should involve, ideally, all important stakeholders of the local waste management.

12.2.6 The democratic challenge in Tandil

As to the *democratic challenge* (and the transformation knowledge), our investigation was influenced by several emerging situations. First, by the creation in 2016 of a boundary organization, a permanent round table for the discussion of the integrated solid waste management (Mesa GIRSU) which congregated different actors, such as councillors from different political parties and representatives of the informal recycling sector. As the objective of this organization was to put under discussion what an adequate waste management framework for Tandil should be and which policies should be adopted to achieve it -fitting therefore with our aim of creating a *transformation arena/agora*-, we decided to focus our interventions or transformational efforts in the context of Mesa GIRSU. Thus, the theoretic development we made when exploring the generation of target knowledge was used as an initial proposal for discussion in the context of Mesa GIRSU. Eventually, it was adopted as the organization’s vision of an adequate waste management framework.

However, the reluctance of the local government to participate in Mesa GIRSU, as well as in any other participative working dynamics we proposed, conditioned the democratic significance of our proposals. This cut short the possibilities of this round table and put us in an opposition role.

Regarding the framework of Figures Figure 53 and Figure 54, we can say that the Engaging action failed (until now), thus severely conditioning our possibilities of making structural changes.

12.3 Achievements and obstacles, future research and action perspectives

The overall aim of this thesis was to enhance the waste management of Tandil, with a special concern regarding the situation of local waste pickers.

The process we analysed and tried to influence in Tandil was the result of changes occurred at multiple levels. Some of these changes facilitated the organization of waste pickers (such as the CSS), and others, as the reluctance of the local government to follow the legislation (and consider and support them), were an obstacle to it. The case of Tandil shows that some progress on inclusive recycling can be achieved with little funding by the local government, when a combination of national policies and local efforts exist. However, the sustainability of the progress achieved needs still to be proved.

If we consider that the evolution of resources management in developing countries is crucial to face the sustainability challenges ahead, and that waste management is a key element of this problem, our experience in Tandil is somewhat troubling. One of the most widespread justifications or explanations for government inaction is the lack of information. In this case, we generated high-quality information regarding the waste management system of the city, and we were prepared to co-create new knowledge regarding the possible futures of the system. However, the information gathered was used neither as an input nor as a decision-making process.

A good question is, therefore, "why was the government so reluctant to use this information, to participate in the proposed activities, or at least to analyse the ordinance projects we presented?" The response is perhaps to be found in the political sphere. As explained in the previous section, there are several lock-in factors which discourage the government to change aspects of the waste management system without paying some political costs. Participative spaces could serve to find ways to overcome these lock-in factors.

Even if MSW is not the biggest challenge of resources management, its importance lies on what it represents for people. Addressing and transforming this relatively "simple" complex problem can help motorize changes in other complex problems (or at least to put them under debate), like the urban and interurban mobility, the food and energy systems, and the water management.

12.3.1 Future research perspectives

As mentioned when we presented the research questions of the thesis, we have more questions at the end of this process than at the beginning. During the writing of our articles, future research perspectives arouse when deepening in each subject.

Regarding the system knowledge, further research may address:

- The role of yerba mate waste in the local context and its treatment alternatives
- The waste characterization of other sources, like commerce or industry
- The co-design of a strategy to manage Construction and Demolition waste
- New insights from qualitative research offering to relate waste generation and socio-economic status or another variable
- The development of a waste characterization method suited to the local context
- The development of MFA-based indicators to be used permanently as a management and monitoring tool
- The best location for the new landfill, which should be operationalized in 2022
- The actual costs associated to the waste management system (we made several estimations but based on limited information)
- A life-cycle analysis of the current recovery schemes, the municipal and the cooperative one
- What are the better alternatives to treat organic waste locally?
- The organization of the work between street waste pickers, their collection routes, the work in the shed and in the sanitary landfill and how we could help to improve these aspects
- How the impacts of the COVID-19 impacted on households' consumption
- How the Complementary Social Salary improved the work and organization of waste pickers in other cities

Regarding transformation knowledge, future research might address:

- The role of the informal sector in waste management, particularly in the context of the "popular economy". One of the PE branches is the "rural branch", which groups small peasants. Together with the waste pickers, they could address the

organic fraction treatment through composting or the production of Black Soldier Larvae, obtaining products that can be used in their garden and farms
- How to implement transitional tools in the context of a city like Tandil, where the local government is reluctant to get involved in this mechanism
- How the institutional structure of the LAE can be better used to promote sustainability
- What institutional mechanisms are adequate to coordinate actions at different levels (local, regional, national) regarding waste management and the circular economy more generally
- How to deal with lock-in mechanisms identified in the mixed-waste regime?
- Which financial mechanisms can help to accelerate a transition to a more sustainable WM system?
- Is it possible to learn from similar and related fields, like Hygiene and Sanitation (H&S) in developing countries? Can we use the "software" tools of H&S in waste management (Peal et al., 2010)? Should we combine action in both fields in Tandil?

12.3.2 Future action perspectives

This thesis deals with a real-world issue which is in a phase of rapid change. As an engaged researcher that is part of these changes, our work will continue, at least while we stay in Tandil. The cooperative of waste pickers can benefit from new types of support and we would like to contribute to this.

Finally, it is important to note that waste is just one of many persistent and complex problems in cities and that they are all interlinked. How cities grow (their population density, the climate performance of their buildings, their public transport, etc.), the characteristics of their food system, i.e. their social metabolism, are important for the construction of a sustainable future. Networking with local environmental associations or NGOs and concerned people to promote a hybrid forum around these complex problems is perhaps the first step to constitute a new transformative agenda.

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2010 - 2012	**Master of Science - Environmental Geosciences**. University of Lausanne (UNIL), Lausanne, *Switzerland*. Specialisation in *Social Environmental Issues*.
2002 - 2008	**Industrial Engineering.** National University of La Plata (UNLP). Buenos Aires, *Argentina.*
Languages	**Spanish**: Native language **French:** Fluent **English:** Advanced (speaking, reading, writing)

WORKING EXPERIENCE

2014 – today	**University of the Centre of Buenos Aires Province**. *Professor (*Industrial Engineering Department). Chairs: Environmental management, Operations research; Global Environmental Issues; Circular Economy: scope, limits and tools.
2016 – today	**Integrated Waste Management Promotion Group (Tandil).** *Coordinator* and Representant of the University of the Centre of the Buenos Aires Province.
2019	**Assessment of the MSW management system of Laprida City**. Consulting. Use of Material Flow Analysis to assess the performance of their recycling facility.
11/2013 – 08/2014	**Cleaner Production Federal Program.** *Consultant***.** Subsecretaría de Control y Fiscalización Ambiental y Prevención de la Contaminación
04/2013 – 10/2013	**Merck Serono (Aubonne).** *Quality assurance Internship***.** Laboratory Information Management Software (LIMS) implementation
11/2006 – 06/2010	**Sanitary Engineering Laboratory**. *Quality manager*. Hydraulic department, National University of La Plata (UNLP)

PEER-REVIEWED PUBLICATIONS

2020	Villalba, L. "Recent evolution of the informal recycling sector in Argentina within the 'popular economy': Measuring its impact through a case study in Tandil (Buenos Aires)". **Waste Management & Research**. https://doi.org/10.1177/0734242X20938437
2020	Villalba, L. "Material Flow Analysis (MFA) and waste characterizations for formal and informal performance indicators in Tandil, Argentina: Decision-making implications". **Journal of Environmental Management** 264, 110453. https://doi.org/10.1016/j.jenvman.2020.110453
2020	Villalba, L., Donalisio, R.S., Cisneros Basualdo, N.E., Banda Noriega, R.B. "Household solid waste characterization in Tandil (Argentina): Socioeconomic, institutional, temporal and cultural aspects influencing waste quantity and composition". **Resources, Conservation and Recycling** 152, 104530. https://doi.org/10.1016/j.resconrec.2019.104530
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	Buenos Aires" in Sagua, M., Calderon, G., Tomadoni, M., 2018. Primeras Jornadas de Hábitat y Ambiente 2016. National University of Mar del Plata, ISBN 978-987-544-768-4
2016	Villalba, L. "Extensión, co-producción y sustentabilidad: convergencia para una transformación necesaria". V Mercosur University Extension Conference. National University of the Centre of the Buenos Aires Province, Tandil

NON-PEER-REVIEWED AND DIVULGATION PUBLICATIONS

2020	Villalba, L. "La crisis del COVID-19 y la Cooperativa de Recuperadores Urbanos de Tandil". **Blog article**. https://www.mesagirsu.org/blog
2019	Villalba, L., Ferrer, A. "Sobre el polémico Decreto de Macri: Argentina no tiene que ser el basurero de las grandes potencias". **Blog article**. https://www.mesagirsu.org/blog
2019	Villalba, L. "Cavas + contenedores = Basurales a cielo abierto". **Blog article**. https://www.mesagirsu.org/blog
2019	Villalba, L., "Medir para poder gestionar ¿Cómo se mide la GIRSU en Tandil?". **Blog article**. https://www.mesagirsu.org/blog
2018	Villalba, L., "De l'effondrement à la collapsologie. Brève histoire du catastrophisme scientifique". **Moins - Journal Romand d'Ecologie Politique**.

SELECTED CONFERENCES AND INTERVENTIONS

2020	**International Solid Waste Association (ISWA) Webinar "Waste Management & Research: The Latest Findings"** 16th September 2020. Presentation of my paper "Recent evolution of the informal recycling sector in Argentina within the 'popular economy': Measuring its impact through a case study in Tandil (Buenos Aires)"
2019	**Transformations 2019. Learning from transformative action and thinking**. *Speaker: "Latin American Extension as Transformative Science for Sustainability"*. University of Chile, Santiago de Chile.
2019	**Working Table on Integrated Waste Management**. *Speaker*: "Tools and strategies for the integrated management of urban solid waste". Buenos Aires Innovation and technology Ministry
2018	**1st Seminar on Circular Economy**. *Speaker*: "Strategies and tools for ISWM". National University of the Centre of Buenos Aires Province
2018	**VI Mercosur Extension Conference**. *Sustainability Round Table coordinator*. University of the Centre of Buenos Aires Province
2017	**Conference « Impulso Regional INTI »**. Speaker: "Household MSW: opportunities for valorisation of the organic fraction". Organized by the National Institute of Industrial Technology (INTI). Mar del Plata.
2016	**1st Open Regional Reflexion Conference on MSW Management**. *Organiser; Speaker: "MSW Management in Tandil"; Workshop Organiser: "ISWM: a complex problem":* National University of the Centre of Buenos Aires Province
2016	**V Mercosur Extension Conference**. *Article presentation: "Extensión, co-producción y sustentabilidad: convergencia para una transformación necesaria"*. National University of the Centre of Buenos Aires Province
2016	**1st Conference on Habitat and Environment**. *Article presentation: "Indicadores de metabolismo urbano aplicados a la gestión de los RSU en la ciudad de Tandil, Prov. De Buenos Aires"*. National University of Mar del Plata.
2015	**Transformations 2015. People and the Planet in the Anthropocene**. *Speaker: "Risk management and collapse risk concept as transformation tools for sustainability"* Stockholm Resilience Centre, Sweden.

2013	**4th Conference on Sustainability Transitions IST 2013.** *Assistant***.** ETH Zürich

OBTAINED SCOLARSHIPS

2014 – 2016	**Advanced research scholarship**. Scientific Research Commission of the Buenos Aires Province
2010 – 2012	**International Master scholarship**. University of Lausanne (UNIL)
2009 – 2010	**Initial research scholarship**. Scientific Research Commission of the Buenos Aires Province

PROJECTS

2021-2022	**Development of wet panels using recovered EPS for their use in social housing**. Interdisciplinary Oriented Project (PIO). Director. UNICEN
2018-2019	**Composting, fertilizing, nourishing**. Interdisciplinary Oriented Project (PIO). Co-Director. UNICEN
2017-2019	**Blue Points for Inclusive Recycling and Integrated Education**. University Extension Project. Director. UNICEN
2015-2017	**Analysis of the Opportunities of the Cooperative Movement and the Social and Solidarity Economy in the Integral Management of MSW in Tandil.** Applied research project. Co-Director. University Politics Secretary, Education Ministry.

Annex: Published versions of the articles

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Full length article

Household solid waste characterization in Tandil (Argentina): Socioeconomic, institutional, temporal and cultural aspects influencing waste quantity and composition

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ABSTRACT

Household waste generation and composition information is a fundamental input for waste management policy design. In developing countries (DC), however, budget constraints make some characterization methodologies inadequate. Following a methodology specially designed for DC, we performed the first door-to-door municipal solid waste (MSW) characterization in Tandil, a city of 130,000 inhabitants. We stratified households into three socioeconomic status (High, Medium and Low SES) using Geographical Information Systems and census data and performed three one-week sampling campaigns over a year. Results indicate that the generation rate of waste produced in households is 0,401 kg/person/day, less than 50% of the waste arriving at the local landfill. We analysed the normality of data associated with generation rates per category of waste (in kg/person/year) through Shapiro-Wilks tests and Q-Q plots, finding that most of them were normally distributed. Using these categories, we compared strata using ANOVA and Tukey tests, finding that strata waste compositions were similar. We registered a high mass loss during picking analysis -more than 3% in autumn and more than 5% in late spring-, which may be related to organic matter humidity evaporation. We compared daily average mass losses with daily average working-hour temperatures, finding a coefficient of determination r^2 of 0,7. Finally, we analyse the consumption of yerba mate -a typical South American habit- as an important source of organic waste and waste moisture content in Argentina.

1. Introduction

Solid waste management is one of the most challenging activities for municipalities in developing countries (Scheinberg et al., 2010). In Latin America and the Caribbean (LAC) region, where 80% of people live in cities, Municipal Solid Waste (MSW) generation is expected to grow 60% by 2050 (Kaza et al., 2018). At the same time, most LAC countries lack vital information to improve waste management policies (ONU Medio Ambiente, 2018).

Information about waste composition and characterization is a fundamental input for waste management policy design (Christensen, 2011). It is highly accepted that those parameters vary widely, depending on the urbanisation degree, the GDP per capita, the regional food choices, and many other local factors (Edjabou et al., 2015; Tchobanoglous et al., 1982). However, cities in developing countries (DC) frequently miss this information, and waste-related decisions are often taken either blindly, or on the basis of national average rates that may be far from the local reality -if available at all- (Miezah et al., 2015; ONU Medio Ambiente, 2018).

In Argentina, waste characterization is not promoted by the national government and detailed and robust analyses are available only for the City of Buenos Aires, a high-density metropolis of 2.9 million inhabitants (Giorgi et al., 2015). General statistics -segregated by city sizes- are available (ARS, 2012), but their usefulness can be only partial and contested because they are calculated as averages of cities belonging to very different geographical areas.

Although there is a wide variety of methodologies for solid waste characterization, obtaining local information is generally not

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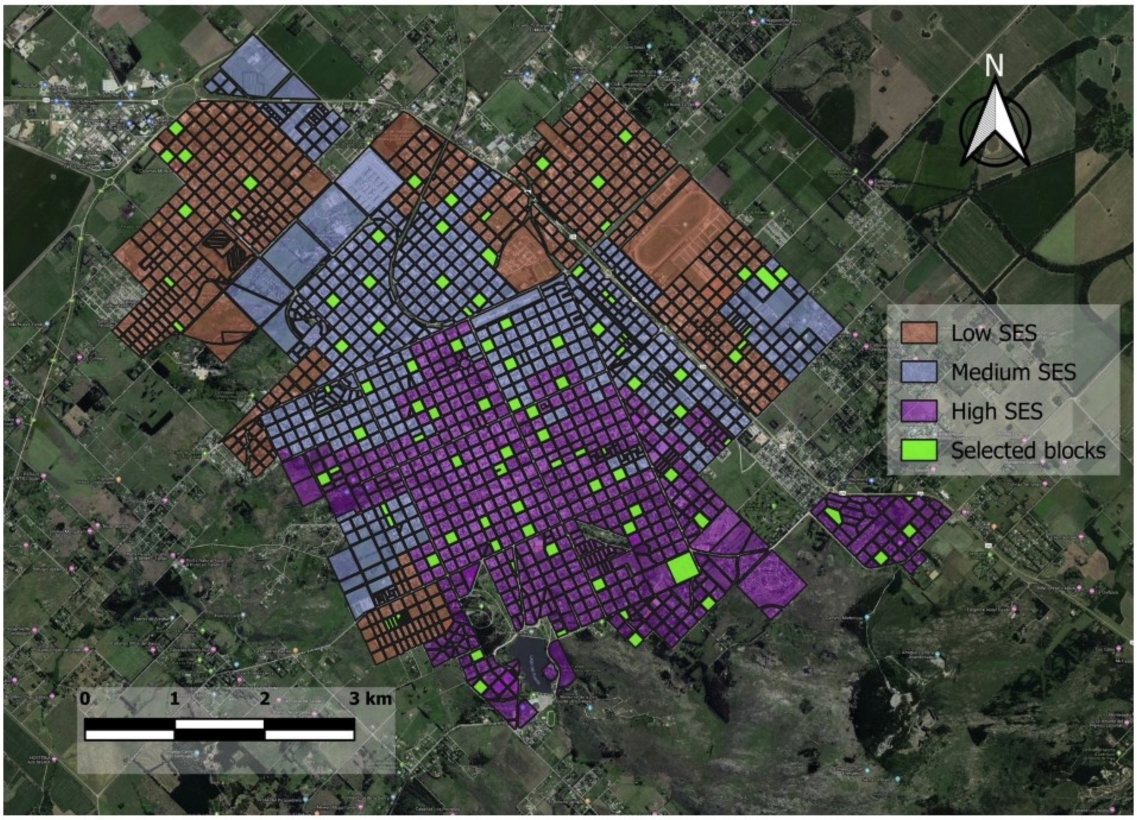

Fig. 1. Map of Tandil with the three defined Socioeconomic Status (SES) strata and the random selected blocks. In the right-down corner, in green, the census blocks removed from the study; in black, those we kept (for interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

straightforward, and special consideration must be taken in developing countries. Flintoff (1980) reviews different methods for MSW sampling in developing countries and analyses how waste information can be lost at every stage of the waste management process. From generation at households to deposition at landfilling, the feeding of animals with food waste and the work of wastepickers are the main sources of waste information loss (ibidem).

Dahlén and Lagerkvist (2008) reviewed and analysed eighteen methods for household waste composition studies based on physical sampling (see below) and two methods based on material flows (e.g. Franklin and Associates, 1999; see also US EPA, 2006). The use of methods based on material flows (indirect measurements) need accurate market information (Baccini and Brunner, 2012; Brunner and Ernst, 1986), which is hard to obtain at the local level and more generally in DC. In Argentina, for example, the shadow economy represents more than 25% of the GDP (Schneider et al., 2010), making the use of this kind of methods inappropriate.

Within the direct physical methods, some focus on the overall Municipal Solid Waste (MSW), that is, waste generated in households and similar waste generated in other sources like offices, public facilities, and commerce (e.g ASTM, 2016 [2003]; Reinhart and McCauley-Bell, 1996), while others focus only on a single source, such as households. As an example of a direct physical method, the ASTM (2016) test is of interest because it is the source of available data for Argentina (CEAMSE, 2016; Giorgi et al., 2015) and because a corresponding standard document is available in the Argentinean Institute of Normalization and Certification (IRAM, 2003). According to this method, the primary sampling units are MSW collection vehicles and the survey should last, at least, a week.

Sampling vehicle loads present, however, some limitations that make them particularly inappropriate for little or medium size cities of developing countries. For example, important equipment such as the front-end loader, should be available or rented. Also, recyclable waste can be collected by wastepickers before trucks collect the waste (Flintoff, 1980), compaction can hinder waste analysis (European Commission, 2004), stratification can be affected (Sahimaa et al., 2015), and deciding on the number of samples can require a large amount of historical data, which may be unavailable. Importantly, some waste fractions may be not normally distributed, suggesting more advanced statistical computation (Edjabou et al., 2017; Lagerkvist et al., 2011). Finally, the information obtained is limited because it is hard to associate the sampled waste with the source and number of people who generated it (Dangi et al., 2008). This information can be precious if recycling strategies target only a sector of the waste management system, such as only households or only commercial activities.

Waste characterization methodologies designed for developing countries are generally focused on a single source, households (Cantanhede et al., 2005; Dangi et al., 2011, 2008; Mbande, 2003; Miezah et al., 2015; Sakurai, 1983). They are intended to be of simple application and requiring only basic instruments and materials. Also, they allow to avoid the mentioned shortcomings of methods sampling vehicle loads.

In this work, we present the results of a study conducted with the overall aim of evaluating the characteristics of waste composition and generation rate of households from Tandil city (Buenos Aires), following the Kunitoshi Sakurai's methodology for MSW analysis (Sakurai, 1983). Stemming from this overall aim, our specific objectives were: 1) to perform a stratified house-to-house characterization of waste under budget constraints; 2) to evaluate the quality of obtained results and compare them with other studies; 3) to analyse the relation between these results and local cultural habits.

2. Material and methods

2.1. Study area

Tandil city is located at the southeast of Buenos Aires province (37° 19.5′S; 59° 08.3′W). It is the head city of Tandil county, which includes four other towns. In 2010, the city had 116,500 inhabitants living in 40,756 households (Edwin and INDEC, 2012). With a total urban area of approximately 50 km^2, the city follows a sprawl model of growth (Fernández and Ramos, 2013), as other Latin American cities (Inostroza et al., 2013; Rojas et al., 2013). Fig. 1 shows the city map, where we can see the typical square households blocks as most cities in Argentina.

Tandil has two different waste management systems: one for mixed waste and the other for source-separated waste. For mixed waste, the city counts with a public kerbside collection service, covering the whole city with different collection frequency. Households, institutions, stores, etc., dispose their daily waste in plastic bags that are initially disposed at sidewalks, since waste bins are not used. Municipal compactor trucks collect the bags at the sidewalks and transport them to a sanitary landfill operated by a private company.

For source-separated recyclable materials, a bring system with three central collection points operate since 2015. These so called "Clean Points" receive, from households: paper and cardboard, glass, plastics (PET and PEAD), tetra brik containers, metals and WEEE. These materials are processed and sold by civil societies to finance their activities.

2.2. Main features of Sakurai's methodology

The formula to determine the number of samples, i.e. households needed, is based on the household waste generation rate (HWGR). For a 95% of confidence level, the formula is:

$$n = s^2/[(ex/1.96)^2 + s^2/N] \quad (1)$$

where s is standard deviation of HWGR; e is the allowed error for the estimation (in percentage) of the HWGR and x is its mean value; N is the total number of households. If previous data is unavailable, estimation of HWGR mean and variance value is needed. Sakurai recommends doing a stratified random sampling based on socioeconomic information.

The study is developed along 8 consecutive days, but the first day is discarded. A proceeding of coning and quartering is suggested to homogenize samples before the calculation of volumetric weight. Subsampling or sieving of samples are not recommended. Furthermore, analysis of waste composition is not done for each bag or household but for each stratum.

2.3. Planning of the sampling

We defined the number of categories for waste classification considering which materials are recycled in Tandil and how they are processed. In this way we narrowed the scope of the study and improved the statistical significance of results (Dahlén and Lagerkvist, 2008). Glass, for example, is not separated by colour; a unique category of glass was therefore defined. As recovered plastics are PET and PEAD collected separately, we defined plastic fractions as PET, PEAD and Other plastics. All categories are listed in Table 1.

2.3.1. Determination of the number of samples

For the application of the Eq. (1), two basic parameters need to be assumed: 1) the mean x of the HWGR (in kg/person/day), to set the desired accuracy of results based on the percentage of error e, and; 2) the standard deviation s of the HWGR.

To estimate the HWGR mean, we first analysed the amount of waste monthly collected by trucks coming from households and commerce in the period 2010–2015 (see Table SI.1 of Supplementary Information). For 2016, a municipal solid waste landfilled rate (MSWLR) between 0.75 and 1 kg/person/day was estimated.

On the basis of previous data (see for example Bernache-Pérez et al., 2001; Buenrostro et al., 2001; Byamba and Ishikawa, 2017; Miezah et al., 2015), we estimated that households contributed with 50–80% of waste arriving to the landfill, i.e. a HWGR within the range [0.375–0.8] kg/person/day. We carried out a simple sensitivity analysis to evaluate how the number of samples required varied according to different values of the HWGR mean, the percentage of error and the standard deviation, for a confidence level of 95% (see Table SI.2 of Supplementary Information). Considering the results of this analysis and considering resource and time limitations, we finally aimed to sample an average of 80 households.

2.3.2. Determination of socioeconomic strata using GIS

We used the national census data (Edwin and INDEC, 2012) mapped with ArcGIS to stratify households according to their socioeconomic status (SES). Census data is aggregated at the lowest level in census blocks, grouping 300 dwellings in average (INDEC, 2015). As there is no income data in the national census, we selected 14 variables related to educational, social, and housing conditions (see Table 2).

Using the ArcGIS tool Grouping Analysis, we grouped similar census blocks according to these variables. We merged the map of census blocks with the map of the city square blocks and checked for overlapping. The resulting map is shown in Fig. 1. In the Supplementary Information we provide further explanations of this step.

We removed the low-density census blocks (in green at the right-down corner of Fig. 1) because it would have been operationally impossible to include households from them in the study. This meant a two-third reduction in the work surface, resigning only 3.6% of households. The structure of each stratum and the corresponding targeted number of samples is detailed in Table 3.

2.3.3. Systematic random selection of the city blocks

As a complete list of dwellings was unavailable, we used the list of the city square blocks as the sampling primary unit. We defined a selection step (p) as the ratio between the total number of square blocks in the stratum (N_h) and the number of samples to be taken from it (n_h). To make sure we had enough HH, we added +10% to the calculated samples (e.g., instead of 31 samples for the High SES, we selected 34). We then generated one randomized number with a spreadsheet (n_a) for each stratum, and following the Eq. (2) we obtained the selected square blocks from the list ($S_{h,i}$).

$$S_{h,i} = 1 + \mathrm{ENT}(n_a{*}p + n_{h,i}{*}p) \quad (2)$$

where $n_{h,i}$ is the number of the sample (going from 0 to $n_h - 1$).

Selected blocks are shown in green in Fig. 1.

2.4. Household recruitment

The recruitment campaign was carried out some days before the beginning of each study. For each randomly selected square block, we started from a predetermined corner and invited the dwellers of the second house of the block to participate in the study. In case they refused to participate, it was an abandoned house or a commerce, or nobody answered, we continued with the next HH. When a HH dweller accepted to participate, we followed the training protocol and gave them 8 plastic bags where the stratum code of the HH was indicated. Finally, we asked for contact information and asked about number of dwellers and age range (< 6; 6–18; 19–60; > 60). This information was used to check the representativeness of the population covered by the sample (see Section 3).

Table 1
Selected fractions for the characterization of the household waste.

Fractions	Description
Organic waste	Mainly food waste and biodegradable waste not fitting in other categories (i.e., used table napkins)
Gardening waste	Biodegradable waste from domestic gardens
Paper	Office paper, notebooks, glossy magazines, etc.
Cardboard	Mostly packaging board, corrugated or not
Tetra Brik	Packaging waste made of Tetra Brik
Plastics	
PET	Polyethylene terephthalate; mainly bottles of domestic use
PEAD	Density polyethylene; mainly bottles of domestic use
Other plastics	Films and other plastic packaging, plastic objects, etc.
Glass	Mainly wine bottles and jam jars; other glass objects
Textiles	Clothes and sewing waste
Metals	
Aluminium	Cans, aluminium wrapping foil, etc.
Ferrous metals	Cans, food containers and other objects
Special waste (SW)	
WEEE	Phones, lighting bulbs, cables, battery chargers, etc.
Batteries	Single batteries/accumulators, rechargeable and not
Others SW (OSW)	Other household hazardous waste
Sanitary household waste (SHHW)*	Diapers, hygienic paper, pharmaceutical waste, dead animals, animal excrement, cat litter, etc.
Refuse miscellaneous waste	All waste not fitting in other categories

* For second and third sampling campaigns we included some sub-categories of SHHW, but their analysis is out of the scope of this paper.

Table 2
Information of the national census used to build the stratification.

N°	Census data variable
1	Illegal occupation
2	Overcrowding – Less than 0.5 persons per room
3	Overcrowding – More than 3 persons per room
4	Index of the quality of materials IV (CALMAT IV)
5	Index of the quality of materials I (CALMAT I)
6	House type – Hut
7	House type – Rancho
8	Houses with Unsatisfied Basic Needs
9	% Unemployed
10	% Employed
11	Academic achieved degree – Postgraduate
12	Academic achieved degree – University
13	Academic achieved degree – Tertiary
14	Academic achieved degree – Never assisted to school

Table 3
Strata characteristics and corresponding number of samples targeted.

Socioeconomic Status (SES)	% of HH 2010	% of people	Number of samples
High	43.20	38.92	31
Medium	37.43	37.84	30
Low	19.37	23.24	19

2.5. Sample collection and processing

Each characterization campaign was carried out from Sunday to Sunday. We established four collection routes including approximately 20 HH each. This allowed us to use private cars for collection, thus minimizing costs. Waste collected the first day was discarded.

Once all collection routes were finished, we regrouped waste by stratum and weighed it on a daily basis. Then, for each stratum, we opened the plastic bags and performed the procedure of coning and quartering with the purpose of measuring the volumetric weight. All waste was processed in what followed, in order to avoid errors from waste splitting (Dahlén and Lagerkvist, 2008; Edjabou et al., 2015; European Commission, 2004).

The next step was picking analysis, in which the stratum waste was classified in the defined material fractions. For special cases during sorting analysis (e.g. packaging items with contents or items consisting mainly of one category but with small parts of other), we mainly followed the recommendations of the SWA-Tool (European Commission, 2004).

After classification of all the waste of one stratum, each fraction was weighed. Mass losses were calculated as the difference between weighed waste before and after sorting process.

2.5.1. Calculation of HWGR and waste composition

For the calculation of HWGR, we considered the quantity of waste generated by each stratum daily and the associated number of people who generated it. As recommended by the SWA-Tool, for the calculation of overall results of each campaign, measures of the single strata were weighed “according to its portion in the parent population” (European Commission, 2004, p. 26). In this way, average results were calculated as “the weighed mean of the single stratum results.” Standard deviation measures correspond to how composition and HWGR per stratum varied daily.

Waste composition data is presented as percentages of wet mass as suggested by Edjabou et al. (2015) and the SWA-Tool (European Commission, 2004) and also on mass per capita and day for fractions -such as organic waste in kg/person/day- for the strata comparison. In this way we avoided the constraints related to closed datasets analysis (see Edjabou et al., 2017).

2.6. Second and third characterizations

The first study took place from June 5th to June 12th, 2016, the second study from December 11th to December 18th, 2016, and the third campaign from April 23rd to April 30th, 2017. Though the three waste characterization campaigns followed the main steps described previously, ~30% of households were renewed in each campaign.

3. Results and discussion

3.1. Sample evaluation

After each recruitment campaign, we compared the age-structure of the population sampled with the age-structure of the city population stated by the 2010 national census (Edwin and INDEC, 2012). The 19–60 age range percentage was the most stable during the three campaigns and also the closest to the census corresponding percentage: 53.87, 53.85 and 53.68% in each sampling campaign against 54.7% in the 2010 census. The 6–18 age segment was the second most stable

Table 4
Waste composition by campaign and stratum, in percentage of wet weight. In the last rows, for each campaign and stratum: average HWGR in kg/person/day; average number of HH and of people that participated.

	End of autumn 2016				End of spring 2016				Beginning of autumn 2017				
	High SES	Medium SES	Low SES	Average	High SES	Medium SES	Low SES	Average	High SES	Medium SES	Low SES	Average	**General average**
Organic waste	57.20	55.25	51.92	55.24	55.21	52.70	52.91	53.72	50.30	49.15	60.78	52.3	53.75
Gardening waste	0.22	0.60	0.91	0.52	2.24	6.88	1.06	3.72	1.63	7.49	1.30	3.77	2.67
Paper	6.26	4.41	4.76	5.21	6.03	3.65	3.84	4.62	4.25	3.69	2.53	3.64	4.49
Board	3.52	3.26	2.41	3.16	3.41	2.32	2.82	2.86	3.13	3.03	2.39	2.92	2.98
PET	1.83	1.96	1.30	1.76	2.31	2.10	2.29	2.23	2.01	1.77	1.64	1.83	1.94
HDPE	0.49	0.59	0.55	0.54	0.55	0.68	1.33	0.78	0.63	0.46	0.61	0.56	0.63
Other plastics	8.79	6.57	6.93	7.52	7.87	6.77	6.94	7.24	7.05	6.81	7.14	6.98	7.24
Glass	7.50	7.58	7.07	7.43	4.91	4.70	5.64	5	10.17	6.94	3.64	7.43	6.62
Textiles	0.89	0.77	2.07	1.12	1.36	2.22	2.43	1.93	1.10	2.00	1.09	1.44	1.5
Aluminium	0.29	0.19	0.25	0.24	0.40	0.22	0.23	0.29	0.38	0.18	0.13	0.25	0.26
Ferrous metals	1.23	0.59	0.83	0.89	0.73	0.95	1.14	0.91	0.94	0.79	0.93	0.88	0.9
Tetra brik	0.79	1.29	1.13	1.06	0.57	0.88	1.72	0.96	0.76	0.92	1.13	0.91	0.98
Other SW	0.35	0.58	0.45	0.46	0.80	0.80	1.10	0.87	0.54	0.49	0.77	0.57	0.63
WEEE	0.04	0.06	0.15	0.07	0.06	0.09	0.16	0.09	0.03	0.25	0.18	0.15	0.1
Batteries	0.01	0.02	–	0.01	0.05	0.00	0.04	0.03	0.15	0.05	0.04	0.09	0.04
Refuse waste	2.96	2.10	3.47	2.75	3.63	4.93	5.14	4.47	6.11	6.40	5.76	6.14	4.45
SHHW	7.65	14.19	15.80	12.02	9.87	10.13	11.22	10.28	10.82	9.58	9.94	10.15	10.82
Average HWGR	0.3108	0.4205	0.3541	0.3624	0.3651	0.4399	0.3553	0.3911	0.4358	0.4336	0.4959	0.4489	0.4008
Average HH per day	32.85	33.42	16.85		30.43	32.57	16.71		26.57	31.86	15.57		
Average people per day	119.00	96.85	63.28		96.28	99.85	56.57		85.14	93.71	47.57		

percentage, with 18.45, 19.23 and 17.28% of sampled people versus 19.93% in the 2010 census. Less than 6 and more than 60 age range percentages were less stable but similar to census 2010 data.

3.2. *Waste composition analysis*

The resulted general composition and HWGR rate for each sampling campaign are shown in Table 4. Organic waste was the main fraction in each campaign, accounting for more than half of the waste. The second predominant fraction in the three cases was SHHW. This may be due to the broad definition we made for this category (see Table 1). Plastics and glass were relevant fractions, too. While participation of some materials remained stable during the three campaigns, such as organic waste, other plastics, metals or SHHW, other materials showed slight fluctuations. Glass and PET, for example, decreased and increased respectively at the end of the spring. This could be due to a smaller consumption of wine, which is the main source of glass waste, and to a higher consumption of soda beverages.

3.3. *HWGR: comparison with other studies*

HWGR calculated for each sampling campaign and stratum can be seen in the last row of Table 4. While general composition of waste remains approximately stable during the three campaigns, HWGR shows a steady growth. This may be explained by the general lower consumption rate of 2016, when Argentina GDP contracted 1.82%, and by its reactivation in 2017. Consumption levels had fallen abruptly in June 2016 (Ambito Financiero, 2016), month of the first sampling campaign, reaching rates similar to those of the 2001 crisis.

The average HWGR for the three sampling campaigns is 0.4008 kg/person/day, which is similar to results of several studies focusing on households from DC. For Mexico, Buenrostro and Israde (2003) reported an average HWGR of 0.405 kg/person/day for 8 municipalities, while Bernache-Pérez et al. (2001) reported 0.51 kg/person/day for Guadalajara. Miezah et al. (2015) obtained, for municipalities of Ghana, a HWGR of 0.4 kg/person/day. Byamba and Ishikawa (2017) report a HWRG of 0.47 kg/person/day for Ulaanbaatar, and Khan et al. (2016) found a HWGR of 0.41 kg/person/day for the district of Dhanbad, in India. Xu et al. (2016) analysed waste generation rates of households in Xiamen Island, China, and found a lower value of 0.31 kg/person/day, whereas Parizeau et al. (2006) reported 0.34 kg/person/day for Cambodia. For Nepal, Dangi et al. (2011, 2013) report 0.33 kg/person/day for Tulsipur and 0.49 kg/person/day for Kathmandu Metropolitan City.

Other studies in developing countries found higher values for HWGR average. Ojeda-Benítez et al. (2008) reported for the city of Mexicali an average HWGR of 0.98 kg/person/day. This difference may be explained by the fact that, in their sampling procedure, "[o]nly family units or households that provided a minimum of five 48-gal plastic bags containing the solid waste generated on a daily basis were included" (Ojeda-Benítez et al., 2008, p. 995).

3.4. *Comparison between strata and data quality*

In order to compare strata, we first calculated the daily HWGR of each waste category (e.g. organic waste in kg/person/day, based on data corresponding to 21 days of work) and the daily average of total HWRG, for each stratum. Then, we analysed the normality of data associated to each category through a Shapiro-Wilks test. The test results showed that the hypothesis of normality should be discarded only for gardening waste, WEE and batteries for the High and Medium SES, whereas in the case of Low SES, the hypothesis should also be discarded for the category aluminium. All other generation rates of individual waste categories were normally distributed in the three strata. The Q-Q plots of main waste categories are shown in Figure SI.2 of the Supplementary Information. The r value of each Q-Q plot is included in Table 5.

Table 5 summarizes, for each stratum, the mean values, standard deviations, and confidence intervals (95% confidence level) for the normally distributed fractions and for the average HWGR. With respect to HWGR average, our results are consistent with the findings of other studies about the higher generation rate in the Medium SES group (Khan et al., 2016; Ojeda-Benítez et al., 2008). When analysing in which categories the generation rate in Medium stratum is higher, we observed a clear difference for the gardening waste. This may be due to housing or behavioural specificities associated to this stratum.

Table 5
Waste generation per category. Mean, standard deviation, 95% confidence interval (Inferior and Superior Limits; IL, SL) and r coefficient of Q-Q plots for each generation rate results distribution.

	High SES (all values in kg/person/day)					Medium SES (all values in kg/person/day)					Lower SES (all values in kg/person/day)				
	mean	sd	IL (95%)	SL (95%)	rQ-Q plot	mean	sd	IL (95%)	SL (95%)	rQ-Q plot	mean	sd	IL (95%)	SL (95%)	rQ-Q plot
Organic waste	0.199	0.029	0.186	0.212	0.979	0.227	0.030	0.213	0.240	0.990	0.223	0.074	0.189	0.257	0.939
Gardening waste[a]	0.005	–	–	–		0.021	–	–	–		0.006	–	–	–	
Paper	0.020	0.004	0.018	0.022	0.993	0.016	0.006	0.014	0.019	0.986	0.016	0.008	0.012	0.020	0.970
Board	0.012	0.005	0.010	0.015	0.967	0.012	0.004	0.010	0.014	0.988	0.010	0.004	0.009	0.012	0.921
PET	0.008	0.003	0.006	0.009	0.978	0.008	0.002	0.007	0.009	0.954	0.007	0.003	0.006	0.008	0.981
HDPE	0.002	0.001	0.001	0.003	0.981	0.002	0.001	0.002	0.003	0.970	0.003	0.003	0.002	0.005	0.958
Other plastics	0.029	0.005	0.027	0.031	0.987	0.029	0.005	0.027	0.031	0.975	0.028	0.009	0.024	0.032	0.920
Glass	0.029	0.020	0.019	0.038	0.927	0.027	0.015	0.020	0.034	0.953	0.022	0.012	0.016	0.027	0.948
Textiles	0.004	0.004	0.003	0.006	0.927	0.007	0.005	0.005	0.009	0.971	0.007	0.005	0.005	0.010	0.937
Aluminium[b]	0.001	0.001	0.001	0.002	0.985	0.001	0.001	0.001	0.001	0.916	< 0.001	–	–	–	–
Ferrous metals	0.004	0.002	0.003	0.004	0.974	0.003	0.002	0.002	0.004	0.981	0.004	0.003	0.003	0.006	0.967
Tetra brik	0.003	0.001	0.002	0.003	0.955	0.004	0.001	0.004	0.005	0.978	0.006	0.003	0.004	0.007	0.967
Other SW	0.002	0.002	0.001	0.003	0.962	0.003	0.002	0.002	0.004	0.960	0.003	0.003	0.002	0.004	0.942
WEEE[a]	< 0.001	–	–	–	–	< 0.001	–	–	–	–	0.001	–	–	–	
Batteries[a]	< 0.001	–	–	–	–	< 0.001	–	–	–	–	< 0.001	–	–	–	
Refuse waste	0.017	0.011	0.012	0.022	0.915	0.020	0.013	0.014	0.026	0.937	0.019	0.009	0.015	0.023	0.994
SHHW	0.036	0.015	0.029	0.042	0.971	0.050	0.021	0.041	0.060	0.924	0.046	0.027	0.033	0.058	0.932
Average HWGR	0.371	0.067	0.340	0.401	0.969	0.431	0.061	0.403	0.459	0.954	0.402	0.100	0.357	0.448	0.948

[a] Results of the HWGR not normally distributed in all strata.
[b] Results of the HWGR not normally distributed only for Low SES.

We carried out an ANOVA and Tukey test for each normally distributed HWGR fraction in order to compare strata. Only one category -tetra brik- showed a significant statistical difference for High SES, where HWGR is lower than in the other strata. This absence of significant difference between strata is consistent with results of other studies (Gomez et al., 2008; Khan et al., 2016; Miezah et al., 2015; Xu et al., 2016).

3.5. *Mass losses and moisture content: the singularity of yerba mate?*

Mass losses were calculated daily for each stratum as the difference between the weight of the waste when entering the process of coning and quartering and the sum of the weights of all sorted fractions. The average mass loss -in percentage- and its standard deviation (sd) for each campaign were as follows: 3,12 (sd = 0.86), for the end of autumn; 5,40 (sd = 1.72), for the end of spring; 3,76 (sd = 0.67), for the beginning of the autumn.

These values are high when compared with the 1,7% reported by Edjabou et al. (2015) and with the maximum of 3% allowed by the standard of waste composition analysis from the Austrian Standards Institute (Lebersorger and Schneider, 2011). The main source of these values may be the loss of moisture of the waste (evaporation) during its processing. Evaporation is affected by temperature, wind speed, and the air humidity. Since wind speed and air humidity are strictly local phenomena and where not measured, we asked the hourly temperature records of Tandil for the 21 days of characterization to the National Meteorological Service. We computed the daily average temperature for the hours in which the work was performed (12–17 h) and plotted it against the average mass loss of the day (see Fig. 2). A determination coefficient r^2 of 0.7 was obtained.

This important loss may be also associated with a very singular habit of the South American region: the consumption of yerba mate infusion. Mate is a hot infusion prepared with the dried and finely ground leaves and twigs of the ilex paraguariensis St. Hilaire tree (normally in particles of less than 3 mm and up to 35% in form of powder). Mate is prepared in a calabash or metal gourd and drunk with a metal straw. After its use, the used (wet) yerba is usually thrown away with mixed waste.

The Yerba Mate National Institute statistics (INYM, 2018) states an average consumption of 6 kg/person/year of yerba mate, which represents a significant amount of related waste considering that once used, i.e., wet, the yerba residue triples the weight of the dried yerba (Gullón et al., 2018). In terms of waste, this means that an average of 18 kg/per/year are generated, of which 2/3 is water.

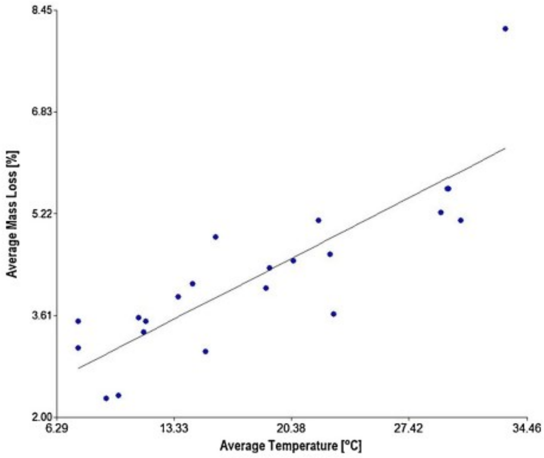

Fig. 2. Regression analysis plot of the average mass loss [%] of each day (three daily measures, one for each strata) and the average temperature registered during of the working hours of the day (12–17 h). Source: our study and the Meteorological Information Centre of the National Meteorological Service of Argentina.

When compared with the ~320 kg/person/year of MSW arriving to the landfill (see supplementary information), this amount of waste represents ~6%. Assuming that the overall composition of MSW is similar to that of the HHW with about 53% of organics (~170 kg/per/year), it could be more than 10% of this fraction which may be due to the consumption of yerba mate.

This is consistent with the experience we had during the picking analysis, where yerba mate was really abundant and adhered to other materials, losing its moisture fast when dispersed.

4. Conclusions

The characterization of solid waste carried out in Tandil shed light on the composition and amount of waste generated in households. An average of more than 80 households stratified according to three distinct socioeconomic status (High, Medium and Low SES) participated in the study. Each sampling campaign took place during one week: in late autumn 2016, in late spring 2016, and in early autumn 2017. It was the first door-to-door characterization of solid waste in Tandil.

Organic waste was the higher fraction in each stratum, representing more than half of the total generated waste. High mass loss during waste analysis was constantly measured. This may indicate that the organic fraction had an important moisture content. Preliminary research based on market information indicates that yerba mate waste is an important contributor of organic matter in Argentina and probably also in other southern countries of Latin America. Further research would better assess the role of yerba mate waste in the local context.

While overall composition of waste remained mainly stable during the three sampling campaigns, household waste generation rate (HWGR) increased steadily. The average HWRG was 0.4008 kg/person/day, the lowest value of the first sampling campaign (0.3618 kg/person/day) and the higher of the last one (0.4506 kg/person/day). This difference may be explained by the lower consumption rates of 2016 in Argentina, and the subsequent economic recovery of 2017. According to these values, households contribute less than 50% to the overall MSW landfilled. Further research is needed to know the amount and composition of household waste generated in other sources.

Medium SES stratum showed the higher average HWRG: 0.4314 kg/person/day. Per capita generation rates by category of waste and stratum were analysed in their normality, results showing that most of them were normally distributed. This information was used to compare strata. However, no statistically significant differences were found. This may be related to the high degree of urbanization of the sampling zone despite SES differences (Xu et al., 2016). Complementary qualitative research is needed to better understand these aspects.

Further research is needed to find a procedure of waste analysis adequate to the characteristics of local waste. Moisture and yerba mate contamination of dry materials, mostly paper and board, were not measured but may be relevant. A procedure of sieving or drying and sieving could be suitable to improve data quality, but budget constraints make these methods unfeasible. Alternately, a separate collection of wet and dry waste for waste analysis may be adequate to lower contamination, but this would require supplementary efforts of people participating in the study.

Declaration of Competing Interest

The authors declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.resconrec.2019.104530.

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Research article

Material Flow Analysis (MFA) and waste characterizations for formal and informal performance indicators in Tandil, Argentina: Decision-making implications

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A R T I C L E I N F O

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Buenos aires province

A B S T R A C T

In cities, the achievement of waste-related legal requirements and the main drivers of Integrated Sustainable Waste Management (ISWM) need adequate indicators and adaptable-to-case tools and strategies. In this work, we combine Material Flow Analysis (MFA) and waste characterizations to develop a mass balance table to design, calculate and analyse indicators related to the formal and informal waste sub-circuits of Tandil, a medium-sized city of the Buenos Aires province (Argentina). Results show that global recovery is very low (2.3% ± 0.16) and mainly driven by the Informal Recovery Sector (IRS). Also, the IRS strategy is more effective, recovering 40% ± 8.0 of its targeted materials from non-household sources. Regarding each material recovery performance, results show significant differences. For paper and board, recovery exceeds 20%. For HDPE, Tetra brik and Ferrous Metals are lower than 1%. In the case of PET and Glass, 9.6 and 9.0% of what is generated in households is recovered, respectively. However, the global recovery rate of each material is different: 2.9% ± 0.4 for PET and 5.5% ± 1.4 for Glass. Our research show that strategies in place are insufficient regarding legislation in force. Even a hypothetically 100% effectiveness in them will account only for 20.9% ± 2.1 of global recovery. Addressing organic waste, therefore, is imperative. Considering the current province law provision of final disposal diversion, accounting for the work of the IRS is key because they recover more waste than the official strategy. Regarding open dumps eradication, we estimate that up to 17% of generated waste is incorrectly final disposed through private skips illegally dumped. A tracking system for skips could avoid this situation.

1. Introduction

From the Agenda 21 (United Nations, 1992) to the 2030 Agenda (United Nations, 2015), waste management (WM) has been recognized as a critical component of sustainable development. However, relatively recent changes, such as the increased complexity of materials and goods (Singh et al., 2014), the massive use of Electric and Electronic Equipment (Baldé et al., 2017), and the exponential growth of waste generation rates (UNEP and ISWA, 2015), among others, have deepened the concern about achieving a global circular economy (Geng et al., 2019; Stahel, 2016), in which waste management plays a key role (European Commission, 2015).

Beyond general considerations though, waste management remains a local issue, facing non-standardized governance and technical challenges related to the main drivers of an Integrated Sustainable Waste Management (Scheinberg et al., 2010; Stanisavljevic and Brunner, 2014; Wilson et al., 2015): the protection of public health and the environment, the management and recovery of resources (3Rs), and the no export of problems to the future (after-care free landfills). Measuring the achievement of these goals and its evolution through adequate indicators needs the implementation of adaptable-to-case tools and strategies (Aljerf and Choukaife, 2016).

Waste process flow diagrams (PFD) are, in this sense, considered as a powerful tool (Scheinberg et al., 2010; UNEP and ISWA, 2015; Wilson et al., 2012) because they allow to represent the main structure of the WM system (WMS) in a simple but comprehensive way (Scheinberg et al., 2010). They consist of identifying processes related to waste (generation, transportation, treatment, disposal, etc.) and flows that connect them within a defined system, and the flows that enter and leave the boundaries of the waste management system (WMS), which are

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generally the spatial boundaries of the city. Some of the key advantages of PFD are that they allow for the identification of main actors of WM and how they relate to each other. At the same time, they show the destination of different waste streams (Scheinberg et al., 2010).

The PFD of a WMS, when combined with a mass balance, is transformed, in substance, into a Material Flow Analysis (MFA) (Allesch and Brunner, 2015; Brunner and Rechberger, 2017; Christensen, 2011a; Villeneuve et al., 2004). Even if they may be treated as synonyms (Masood et al., 2014), the application of MFA to WMS is a specific and growing scientific niche, with a scope that exceeds the general purpose of a PFD (see Allesch and Brunner, 2015 for a review). MFA can be focused on goods (e.g. mixed waste or a waste category) and/or on substances (e.g. phosphorous). Moreover, the MFA field is advanced in the treatment and calculation of important (but generally absent in PFD) aspects of WMS, like stocks and its variations, uncertainties of flows and stocks, or the standardization of diagrams using specialized software.

As in the case of the PFD, the construction of an MFA implies the acquisition of qualitative information related to actors and processes. However, due to its quantitative nature, it is a suitable base for the calculation of indicators related to the amount of waste entering or leaving a process or the system. Yet, their usefulness will depend on the quality and detail of available information.

In the case of recycling rates, information requirements are mainly related to (EPA, 1997; Ferronato and Torretta, 2019; Hotta et al., 2016; Wilson et al., 2009): a) the structure of the recycling system (formal and informal) b) the amount of waste generated; c) the waste composition; d) the quantity of waste diverted from final disposal. Importantly, the first point determines the level of detail in which the information should be available for the others. If different strategies are defined for different waste generation sources or group of them (i.e. a recycling campaign focused only on households), or at defined spatial sectors (i.e., the most populated sector or defined neighbourhoods), the information related to points b, c, and d should be available at these levels if a proper evaluation of these recycling strategies is desired (Hotta et al., 2016).

Moreover, in the Global South, where informal actors are often relevant to the performance of the recycling system (Ferronato et al., 2019; Wilson et al., 2006), incorporating the flows related to them is crucial. Also, this information is of vital importance to boost the inclusion of the informal recycling sector (IRS) itself in the formal WMS, an aspect that is considered essential to the achievement of circular economy in the Global South (Velis, 2017; Velis et al., 2012). However, measuring these flows can be challenging, because informal activities are -in most cases-part of the shadow economy (Schneider et al., 2010).

In the case of incorrect waste disposition, the challenge may be related to its illegality, to the identification of the source of waste (individuals, trucks, skips) and to the rapid change of the open dumping locations.

In Buenos Aires province, Argentina, where informal recycling and open dumping are part of the WMS of most cities to a greater or lesser extent, relatively recent legislation has compelled municipalities to divert waste from final disposal according to specific targeted-in-time percentages and to eradicate open dumps. However, due to limitations mentioned above, how to measure the achievement of these objectives is not well understood.

In this work, we combine MFA and information obtained through waste characterizations in a mass balance table to design, calculate and analyse recovery and performance indicators of formal and informal recovery strategies in place in Tandil, an intermediary city of Buenos Aires province.

Thus, the objectives of this study were: a) to apply the MFA approach to the WMS of Tandil city by incorporating measurement uncertainties; b) to use this information to conceptualize and calculate the indicators needed to evaluate the recovery potential and current performance of strategies in place (formal and informal); c) to explore, on the bases of obtained results, ways to improve the WMS functioning, regarding the local legislation and the drivers of the ISWM.

2. Materials and methods

2.1. Study area

Tandil city is located at the southeast of Buenos Aires province (see Fig. 1). The last census' projections estimate, for 2019, a population of 137.922 for the county of Tandil, out of which approximately 94% lives in the head city and the rest in four surrounding towns. The predominant soil characteristics, very rich in nutrients, favour the development of dryland farming which, along with animal husbandry, are the main economic activities of the county (Falasca et al., 2002).

2.2. Tandil waste management system

There are three main municipal solid waste (MSW) circuits in Tandil (Fig. 2): 1) the core system of collection and final disposal of mixed waste, driven by the municipality (Fig. 2b); 2) the recovery of recyclable materials, historically conducted by waste pickers (Fig. 2c) and, since a few years ago, also by non-profit organizations (NGOs, civil associations, etc.) with municipal support (Fig. 2a), and; 3) the private containers service circuit (Fig. 2d).

In the first, MSW is initially disposed in plastic bags at sidewalks, collected by compactor trucks and end-disposed in a sanitary landfill. Collection coverage rate is approximately 100%, decreasing occasionally if an offset occurs between the city growth and the planning of collection routes. People and enterprises can also bring waste directly to the landfill, but compared to the main collection system, this is negligible.

The second recovery-for-recycling circuit can be divided into a formal and an informal sub-circuits. In the formal sub-circuit, recycling waste is disposed by citizens in collection facilities under a bring system. These so-called "Clean Points" are managed by the municipality and receive, from households: plastics (PET and HPDE), paper, board, tetra brik containers, glass, metals, and Waste Electrical and Electronic Equipment (WEEE). WEEE is repaired and reused by the local university or sent for recycle/disposal out of Tandil, and glass is delivered for free to a local intermediary due to its low price. The remaining collected waste is assigned to a different non-profit organization, which depends on the category to which the collected waste belongs. Then, these organizations classify and commercialize the materials, either directly in Tandil or in Buenos Aires city, to which the materials are sent by train. In the informal sub-circuit, waste pickers collect, mainly exclusively from commerce, the materials they can sell directly in Tandil. These materials are paper, cardboard, and scrap metals.

Finally, we can identify the circuit of private skips. They are metal containers of different sizes that private users can hire and that are delivered and removed by special trucks. Although originally this service was intended to provide a mechanism to dispose Construction and Demolition (C&D) waste, the lack of a municipal collection service of voluminous waste has converted this circuit in a destination of all kind of waste. Furthermore, even if its destination is supposed to be the sanitary landfill, numerous open dumps have been detected where private companies empty their containers (see for example ABC Hoy, 2018 or; El Eco de Tandil, 2017).

2.3. Material Flow Analysis

As indicated by Brunner and Rechberger (2017), the construction of a MFA is a goal-oriented iterative process. It starts with a qualitative model and then, by means of improving of rough flows' estimations, leads to a quantitative model that should fulfil the objectives of the study.

Our investigation followed an iterative path, updating the goal of the application of MFA as new information was available. It started with a simple model, aimed at describing and understanding the WM system. This allowed us to identify key actors to be interviewed, key places to be

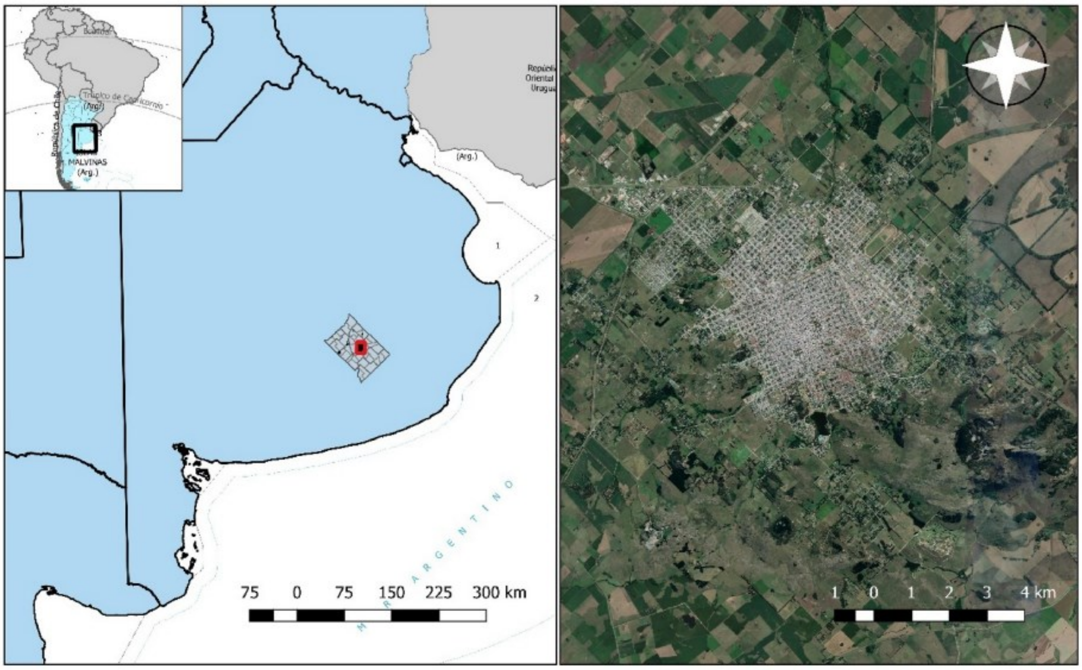

Fig. 1. The county of Tandil (4935 km^2) in Buenos Aires province with Tandil city in red (left) and the city in detail, with its square blocks in urbanized areas, typical of Latin American cities (right). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

visited, and available as well as lacking quantitative information. Then, we started a field work with the IRS of Tandil, and we planned and implemented the first household waste characterization of the city (Villalba et al., 2020). Importantly, our work was also influenced by disruptive information in the local press, such as complaints about illegal open dumps.

With this new information available, we could define new objectives for the MFA, according to the objectives of this study.

2.3.1. System construction

2.3.1.1. Spatial and time boundaries. The clear definition of the system boundaries is crucial (Allesch and Brunner, 2017). For the present study, we decided to focus on the year 2017 because the first waste composition information was available this year and official information is also available for this period. The spatial boundary was defined as the Tandil city.

We consider waste all the flows of material entering to the waste management system as defined in section 2.2. We therefore excluded flows related to the direct selling of discard materials from producers (e.g. paper residues from a printing house) to industry or intermediaries, where there was no intervention of external actors.

2.3.1.2. Processes. As recommended by Christensen (2011b), we included in the system processes related to collection and transport, treatment and landfilling, or open dumping of waste. Only the last two final disposal processes were considered to have a stock.

We considered collection and transportation processes: 1) the municipal service for mixed waste; 2) the private skips' service; 3) the IRS service; 4) the Clean Points.

In the treatment phase, we included the intermediaries and the non-profit organizations that classify and sell the main fractions of recycling waste destined to industries: paper and cardboard, and plastics. Recycling industries or industries that receive this type of waste are excluded from the system because their outputs are not considered waste any more; they are considered raw materials instead.

Finally, in the final disposal phase, we retained the sanitary landfill and a general process "open dumps" related to the incorrect disposal of skips' containers. We therefore dismissed micro open dumps formed occasionally due to incorrect disposal of individual sources.

2.3.1.3. Flows: categories of materials and units. In MFA, flows indicate how the analysed goods or substances enter or leave the system and how they circulate from one/more process(es) to another/others (Brunner and Rechberger, 2017). Their units are mass per time (e.g. ton/year) or mass per time and section (e.g. kg/pers/year). The later are called fluxes instead of flows. In the present work, we will analyse flows in tonnes per year (t/year).

Fig. 3 shows a generic and simplified version of the WM system, constructed by using the STAN software (Cencic and Rechberger, 2008). This software allows for the calculation of the whole system if a minimum number of flows are valued, because it constructs the mathematical model associated to the "drawn" system and applies mass balance and error propagation (Brunner and Rechberger, 2017). Moreover, it supports the inclusion of different layers of goods or substances for the same system.

As different materials are processed to be recycled, we defined different categories of waste to be analysed, corresponding to the main recovered materials: paper, board, PET, HPDE, tetra brick, metals, and glass. We decided therefore to exclude from the analysis scrap metals recovered by waste pickers and WEE arriving to the Clean Points. Each studied material was assigned to a different layer in the STAN model.

2.3.2. Information sources strategy

On the basis of the MFA system defined, and considering the waste categories included in the study (layers of the STAN system), we defined, for each flow and stock, a strategy to obtain the quantitative information related to them. Table 1 presents the information sources, uncertainty estimations and complementary information of each flow and stock of the system.

Fig. 2. a) A municipal Clean Point, where citizens can bring some types of recycling waste (left and centre) and the manual sorting and pressing in the *Taller Protegido* (right). b) Initial disposal in sidewalks (left), the municipal collection and transportation service (centre) and the sanitary landfill (right). c) A waste picker self-made bike-pulled trolley for board collection in the city centre (left) and a motorized waste picker collecting board from a peripheral commercial axe (centre); at the right, an intermediary's shed. d) Private skips containing different kind of wastes (left and centre) and an open dump (right) where part of these skips is disposed (we see in the picture a skip-truck). Photo credits: the author, except for: b-centre (*La Voz de Tandil*) and c-right (Soledad Vidal), with permission.

Uncertainties associated to flows and stocks, in general, are not well addressed in waste management studies (Stanisavljevic and Brunner, 2014) and often neither in MFA publications (Rechberger et al., 2014). For our study, we aimed to assign a percentage of uncertainty to every flow and we supposed all uncertainties to be normally distributed.

In the cases in which we had two sources of information for the same flow, we kept the less uncertain, even when this implied calculating it through mass balance. This was the case for most flows leaving the municipal Clean Points, for which official information of recycling waste delivered to non-profit organizations demonstrated to be highly overestimated.

3. Results and discussion

3.1. Definition of indicators

Based on the MFA system presented in Fig. 3, we aimed at the design of indicators that could help to understand the functioning of the system regarding the objectives of the study. For this, we first conceived a mass balance table, inspired by the Standard Model of Water Loss of the International Water Association (IWA) (Alegre and IWA, 2000), which served to design the indicators described below. Fig. 4 presents the mass balance table and how most of its related indicators are constructed.

3.1.1. Global recovery indicator

A general indicator of waste recovery can be defined on the basis of all waste inputs and all recovery flows (Eq. (1)).

$$GRI = \frac{(F16 + F17)}{(F1 + F2 + F3 + F4)} * 100 \tag{1}$$

where GRI is in % and all flows are in t/year.

3.1.2. Formal and informal recovery indicators

To measure how the IRS and the formal recovery system are contributing to the global indicator defined above, we defined the following indicators (Eqs. (2) and (3)).

$$FRI = \frac{F7 + F13 + F16}{(F1 + F2 + F3 + F4)} * 100 \tag{2}$$

$$IRI = \frac{F9}{(F1 + F2 + F3 + F4)} * 100 \tag{3}$$

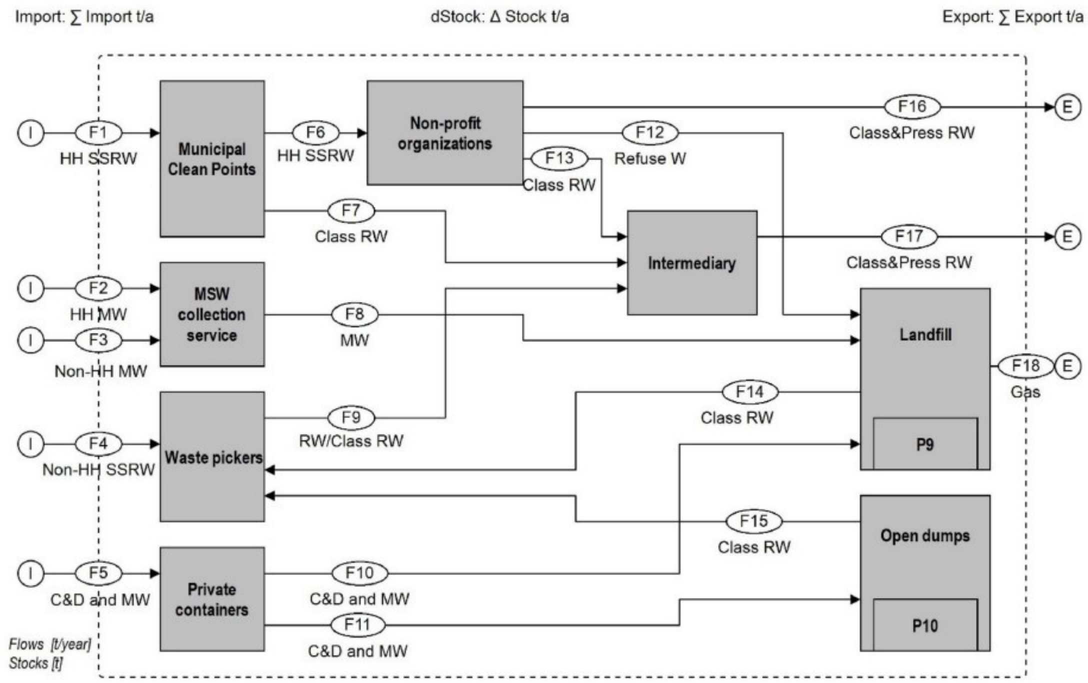

Fig. 3. General system for Tandil constructed with the software STAN (goods layer). Subsequent layers with each waste category under study were created (see Supplementary Information). RW = Recycling waste; Class RW = Classified recycling waste; Class&Press RW = Classified and pressed recycling waste; C&D = Construction and demolition waste; MW = Mixed waste.

where all flows are in t/year and FRI and IRI are in %. By definition, the addition of both will equal the GRI (Eq. (1)).

3.1.3. Maximum recoverable under current strategies (MRUCS) and not recoverable under current strategies (NRUCS)

The global recovery indicator defined in section 2.4.1 is not well suited to evaluate (alone) the recycling performance in Tandil. This is because not all the waste arriving to the system can be recovered. Under the existing recovering strategies (formal and informal), only some materials are dealt with, that represent a fraction of the total input. However, we consider important to measure, first, what percentage of this total input is dealt with through the current targeted materials (see section 2.3.1) at each targeted source (households and other sources) and, second, what percentage is not dealt with (Eqs. (4) and (5)).

$$MRUCS = \frac{\left(\sum F1_{RWi} + \sum F2_{RWi} + \sum F3_{RWj} + \sum F4_{RWj}\right)}{(F1 + F2 + F3 + F4)} * 100 \tag{4}$$

where each RW_i is a waste category flow targeted by the formal circuit (arriving from households) and each RW_j is a waste category flow targeted by the informal circuit.

Importantly, this indicator only considers capacity according to the targeted materials at each source, but does not consider infrastructure, logistics, costs, and other aspects related to a real recovery capacity. It is focused on the limits of current strategies in place. Therefore, what is considered recoverable refers to the current addressed materials.

Complementarily, we can define the Not Recoverable Under Current Strategies as:

$$NRUCS = 1 - MRUCS \tag{5}$$

3.1.4. Effective use (EU) of MRUCS

As we obtained the maximal potential of recovery under current strategies, it is possible to evaluate at which percentage the city is effectively using the MRUCS.

$$EU\ of\ MRUCS = \frac{\left(\sum F1_{RWi} + \sum F4_{RWj}\right)}{\left(\sum F1_{RWi} + \sum F2_{RWi} + \sum F3_{RWj} + \sum F4_{RWj}\right)} \tag{6}$$

3.1.5. Clean Points and waste pickers strategies performance indicators

If we consider that the formal and informal circuits of material recovery are focused on distinct materials and sources, it is possible to measure the effectiveness of each strategy (Clean Points and Waste Pickers) as regards their targeted source of waste. For this, we defined the next two indicators (Eqs. (7) and (8)).

$$CP's\ performance = \frac{\sum F1_{RWi}}{\left(\sum F1_{RWi} + \sum F2_{RWi}\right)} \tag{7}$$

$$WP's\ performance = \frac{\sum F4_{RWi}}{\left(\sum F3_{RWi} + \sum F4_{RWi}\right)} \tag{8}$$

*It refers to the targeted materials under the current functioning of the system.

3.1.6. Individual materials indicators

Finally, having the adequate disaggregated information, it is also possible to calculate, for each material recovered in Tandil, its recovery percentage (Eq. (9)).

$$Recovery\ of\ material\ i = \frac{F7_i + F13_i + F16_i + F9_i}{F1_i + F2_i + F3_i + F4_i} * 100 \tag{9}$$

Complementarily, we analysed: 1) in which percentage the individual material is recovered from each generation source (Eqs. (10) and (11)); 2) in which percentage this recovery is performed by formal or informal actors (Eqs. (12) and (13)), and; 3) in which percentage each material is generated at households or at other sources (Eqs. (14) and (15)).

$$RecHH = \frac{F7_i + F13_i + F16_i}{F1_i + F2_i} * 100 \tag{10}$$

Table 1
Flows and stocks included in the MFA: ID, waste category, source information strategy, level of uncertainty and observations.

ID	Category/ies name/s	Information source/s	Uncertainty considerations	Observations
F1	General flow, Paper, Board, PET, HPDE, Tetra brick, Glass, Ferrous Metals	Mass balance	Calculated through error propagation by the software STAN	General flow is calculated as the addition of all flows' categories and Refuse waste from downstream classifying and/or pressing processes. Uncertainty derived from precision of professional balances used by non-profit organizations and a coverage factor
F2	General Flow, Paper, Board, PET, HPDE, Tetra brick, Glass, Ferrous Metals	Villalba et al. (2020)	Calculated following the recommendations of the SWA-tool for stratified data (European Commission, 2004) and an estimation of the total population of Tandil and its uncertainty	The population of Tandil was taken from the National Statistics and Census Institute previsions for the period 2010–2025 (INDEC, 2015). An uncertainty of 3% has been associated to this estimation.
F3, F4, F5, F6	General Flow, Paper, Board, PET, HPDE, Tetra brick, Glass, Ferrous Metals	Mass balance	Calculated through error propagation by the software STAN	F5 have only the General flow, Paper and Board layers
F7	Glass	Official statistics published by the municipality (MdT, 2019)	15% estimated	Glass is the only category classified at the Clean Point and sent directly to the intermediary.
F8	General flow	Registers from the landfill managing organization	1% assigned to the balance	
	Paper, Board, PET, HPDE, Tetra brick, Glass, Ferrous Metals	From Capparelli (2019), which used a Standard Method to the characterization of mixed waste (ASTM, 2016)	10% estimated upon the percentage obtained by Capparelli (2019)	Example: from Capparelli (2019), paper is 2.44% of waste arriving to Landfill. Thus, we estimated the flow of paper to be 2.44 ± 0.24% of F8 - General flow. For the rest of materials, percentages are: Board, 3.72%; PET, 3%; HDPE. 1.76%; Tetra brick, 2%; Ferrous metals, 1.27%; Glass, 5%.
F9	General flow	Mass balance	Calculated through error propagation by the software STAN	
	Paper, Board	Information given by the intermediary and later validated through data triangulation	10% estimated	Intermediaries can be reluctant to give this information, either because they are evading tax payments or because they are aware of the possible organization of a waste picker's cooperative or similar, for which one of the main goals is to achieve a vertical integration in the value chain, i.e. bypassing middlemen. In our case, from a 2015 interview with the biggest intermediary of the city, we had an estimated value of recovered material by waste pickers that we later triangulated with sources from international literature (Linzner and Salhofer, 2014) and with results of a similar IRS census performed in Mendoza city (Argentina) in 2017 (Usach, 2019)
F10	General flow	Registers of skips from the landfill managing organization	1% assigned to the balance	
F11	General flow	Estimated on the basis of changes occurred in waste arriving to the landfill through skips when a big open dump was closed	15% estimated	We analysed how the closure of a big open dump on the first days of September 2017 (El Eco de Tandil, 2017) affected the quantity of waste arriving this way to the landfill. First, we checked the normality of available historical data (27 months before the closure) through a Shapiro-Wilks test. Then, we calculated its 99% confidence intervals (CI) and found that the quantity of waste disposed through skips the month of the closure tripled the upper limit of the CI.
F12	General flow	Mass balance	Calculated through error propagation by the software STAN	Addition of all flows' categories
	Paper, Board, Tetra brick, PET, HPDE, Ferrous Metals	Assumed to be 15% of waste sent from the Clean Points to non-profit organizations. Because reliable data is that registered in sales made by non-profit organizations (F13 or F16), this flow was calculated as 0.15*[kg sold]/0.85	10% estimated	On the basis of interviews to the organizations and 3 full inspections of PET big-bags sent from the Clean Points to a non-profit organization where miss-classified waste reached in average 15% in weight
F13	General flow	Addition of categories' flows, based on sales registers	Calculated through error propagation	
	Board, Paper	Sales registers	1% assigned to the balance	Information provided by CIANE, the non-profit organization receiving paper and board from the Clean Points
	Ferrous Metals	Official statistics published by the municipality (MdT, 2019)	15% estimated	There is not a systematic weight of materials in the Clean Points

(continued on next page)

Table 1 (*continued*)

ID	Category/ies name/s	Information source/s	Uncertainty considerations	Observations
F14 and F15	General flow	Addition of categories' flows	Calculated through error propagation	
	Paper, Board	Assumed to be each flow 5% of what is recovered by waste pickers (F9)	10% estimated	
F16	General flow	Addition of categories' flows	Calculated through error propagation	
	PET, HDPE	Sales registers	1% assigned to the balance	Information provided by Taller Protegido, the non-profit organization receiving PET and HDPE from the Clean Points
	Tetra brick	Official statistics published by the municipality (MdT, 2019)	15% estimated	There is not a systematic weight of materials in the Clean Points
F17	General flow	Addition of categories' flows	Calculated through error propagation	
	Paper, Board, Glass, Ferrous Metals	Mass balance	Calculated through error propagation	
F18	General flow	LandGEM software	10% estimated	Based on historical registers of the landfill

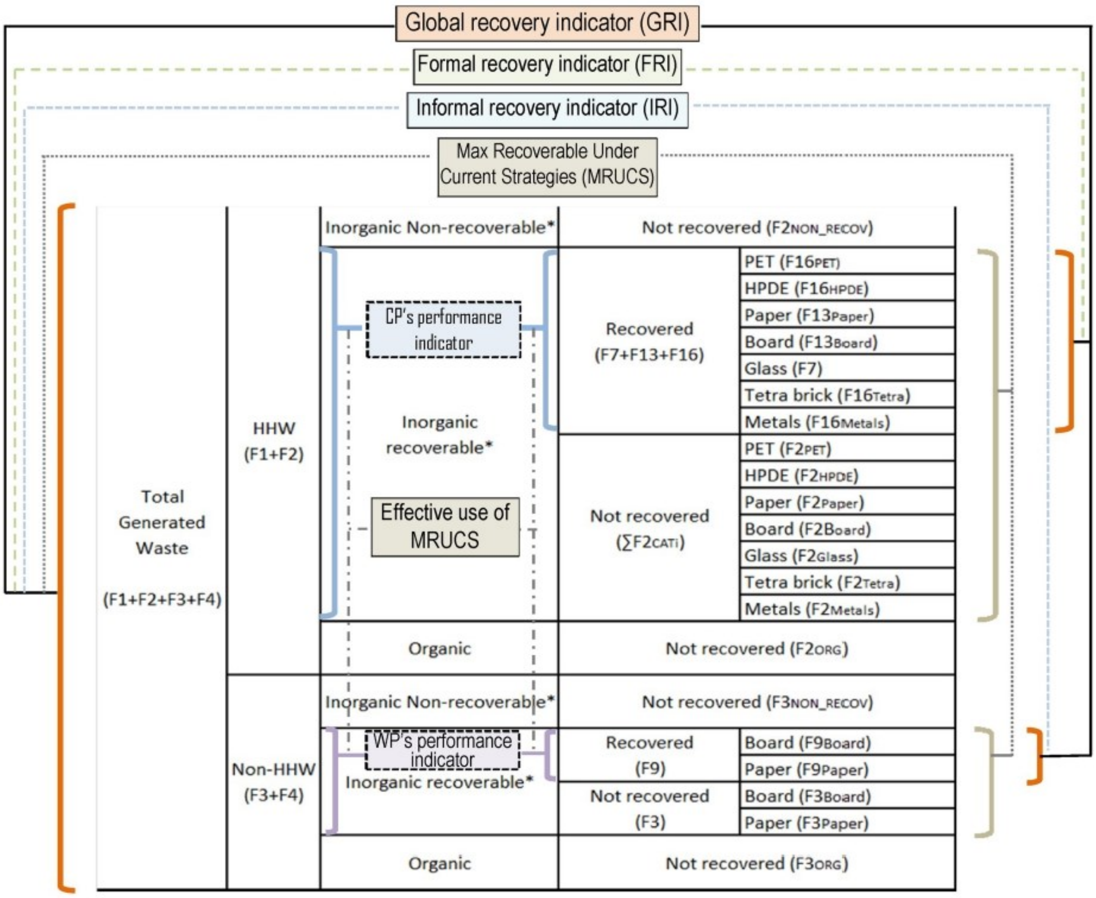

Fig. 4. System mass balance table for the current recovery strategies and all general indicators.

$$RecNonHH = \frac{F9_i}{F3_i + F4_i} * 100 \tag{11}$$

$$Formal = \frac{F7_i + F13_i + F16_i}{F7_i + F13_i + F16_i + F9_i} * 100 \tag{12}$$

$$Informal = \frac{F9_i}{F7_i + F13_i + F16_i + F9_i} * 100 \tag{13}$$

$$GenHH = \frac{F1_i + F2_i}{F1_i + F2_i + F3_i + F4_i} * 100 \tag{14}$$

$$GenNonHH = \frac{F3_i + F4_i}{F1_i + F2_i + F3_i + F4_i} * 100 \tag{15}$$

3.2. *MFA of general flows*

Fig. 5 presents the results obtained from the WMS model by using the STAN software and values obtained from different layers. As the arrows' thickness is proportional to the value of the represented flow, it is easy to observe that the vast majority of waste entering the system is conducted to the sanitary landfill through the MSW collection service process.

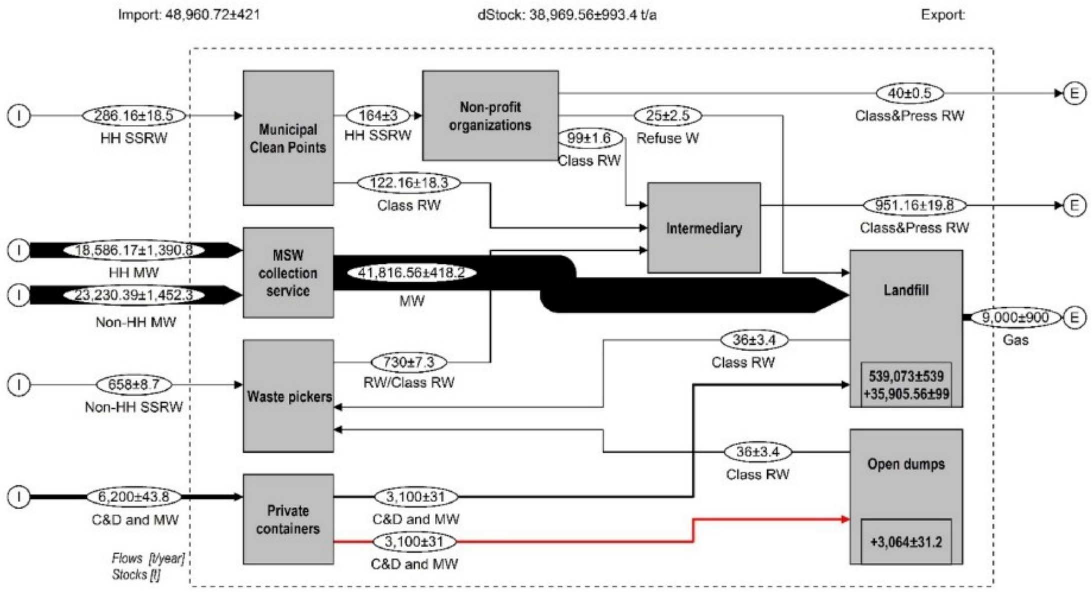

Fig. 5. Results of general flows of the system, presented with STAN. In red, waste disposed incorrectly. RW = Recycling waste; Class RW = Classified recycling waste; Class&Press RW = Classified and pressed recycling waste; C&D = Construction and demolition waste; MW = Mixed waste.. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

3.3. Indicators' results

Tables 2 and 3 present the results of all calculated indicators. We could calculate the associated error of each indicator by means of error propagation rules (Taylor, 1997), which was possible because we could account for flows' uncertainties (Table 1).

As it could be attended on the basis of the general picture obtained through the MFA, the Global Recovery Indicator (GRI) is very low. This is in part related to the recovery potential of the current strategies in place (measured through the MRUCS, not considering infrastructure), which, in the best case, could recover approximately 20% of the total waste entering the system (from households, less than 9%). Considering the GRI, this means that the effectiveness of the current strategies in place is slightly above 10%.

Waste pickers are responsible of more than 70% of the recovered waste in Tandil, according to the system borders' definition. Importantly, this percentage does not account for scrap recovery, which is out of the scope of this study, but on which waste pickers also focus their attention and are highly active. However, our result is consistent with other studies focused on cities from developing countries. Bidegain (2011) signals that 65% of recycled materials in Montevideo is collected by the informal recycling sector, while Scheinberg (2012), analysing more than 10 cities from developing countries, found values above 80% in most cases.

At the same time, when comparing formal and informal strategies performances, i.e. their effectiveness in recovering the materials their target from the source they target, we found that waste pickers are reaching 40% of this indicator, while Clean Points are only reaching 7%. This difference may be due to several reasons: on the one hand, to the experience in material recovering for subsistence accumulated during decades by waste pickers, which made them focus on medium or large generators, with whom they have a personal contact and implicit agreements; on the other hand, the existence of only two municipal Clean Points for the whole city means that, for most households, even if they are willing to recycle, taking materials to one of these two points represents a considerable effort. Table 3 shows the results of indicators related to each recovered material.

Table 2
Results of the general indicators defined in section 2.4

General indicators	Value [%]
Global Recovery Indicator (GRI)	2.3 ± 0.16
Formal recovery indicator (FRI)	0.6 ± 0.07
Informal recovery indicator (IRI)	1.7 ± 0.1
Maximum Recoverable Under Current Strategies (MRUCS)	20.9 ± 2.1
Not Recoverable Under Current Strategies (1 - MRUCS)	79.1 ± 2.1
Effective use of MRUCS	11.1 ± 1.3
Clean Points' performance indicator	7.0 ± 1.0
Waste Pickers' performance indicator	40.0 ± 8.0

Table 3
Results (in %) of indicators defined for each recovered material.

		Recovery by source		Recovery by strategy		Generation by source	
Material	Recovered	HH	Non-HH	Formal	Informal	HH	Non-HH
Paper	21.2 ± 4.2	7.6	50.2	24.4	75.6	70.9	29.1
Board	26.0 ± 4.9	4.5	35.1	5.1	94.9	30.0	70.0
PET	2.9 ± 0.4	9.6	–	100	–	30.8	69.2
HDPE	0.2 ± 0.02	1.2	–	100	–	15.9	84.1
Glass	5.5 ± 1.4	9.0	–	100	–	60.9	39.1
Tetra brik	0.1 ± 0.02	0.4	–	100	–	21.9	78.1
Ferrous Metals	0.8 ± 0.2	2.5	–	100	–	31.8	68.2

Regarding the general recovery performance, paper and board are the best positioned. This is mainly due to the work of waste pickers, which are responsible of a large part of the recovery in both cases, especially in the case of board.

Regarding the functioning of the Clean Points, we see that their performance is higher in the cases of glass and PET, in which they recover almost 10% of what is produced as waste in households. This is not equally reflected in the general recovery indicator of each material because they are generated differently by source: glass is predominantly generated in households, while PET is generated in other sources.

HDPE, in comparison with PET, and even if they are both usually labelled and promoted for recycling under the general denomination of "plastics", has a very low recovery rate. This difference may be due to the "popularity" of PET bottles as recycling waste and to a possible lack of information about the recoverability of HPDE containers by citizens. Further qualitative research would be needed to better understand this aspect.

In the case of Tetra brik and Metals, the performance of the Clean Points is even lower. With the former, this may be due, in part, to the fact that, before 2017, this material was not accepted in the municipal facilities. In the case of ferrous metals (mainly cans), this may be related to the effort needed to clean the cans to avoid bad smells. In both cases, advanced qualitative research is needed to support or reject these assumptions and to find new responses.

When analysing in which source these waste streams are generated, we found that there are clear differences between them. While board is mainly generated in sources other than households, paper waste is mainly generated in households. We think this may be related to the high price of paper, which makes its recovery part of the business of large generators, therefore avoiding the waste management system as we defined it in our MFA system borders.

Most of the other waste streams, except for glass, are mainly generated in sources other than households. This raises concern about the municipal strategy, which is focused on the recovery from households of waste materials mainly generated elsewhere. The high recovery rate of glass, a category mainly generated in households, is rather an exception and may be related to the use of information provided by the municipality, which demonstrated to be highly overestimated in the case of paper, board, and PET.

3.4. *Decision-making implications and policy recommendations*

The assessment methodology we developed in previous sections is applicable to any city for which data is available or can be estimated. The obtained results open the way to exploring how the WMS and current strategies in place respond or could better respond in the future first, to local legislation, and second, to safe disposal and resource recovery practices associated to the integrated sustainable waste management framework (UNEP and ISWA, 2015; Wilson et al., 2015).

3.4.1. *Province legislation*

In Buenos Aires province, the 2010 Law 13,592 of Integrated Solid Waste Management sets two main priorities for municipalities: 1) A total decrease of 30% of the waste sent to final disposal in 5 years since the approval of the ISWM local Plan; 2) the eradication of open dumps.

In relation to the first point, from the analysis of our indicators we can point out two principal observations. First, the importance of considering the performance of informal recovery actors, which is absent in the recovery indicators informed by the municipality (MdT, 2019). Ignoring their work means that the reported recovery in the city is much smaller. Second, the fact that the formal circuit supported by the municipality since 2015 (the targeted materials from the targeted source) can recover, in the best case, less than 9% of the waste arriving to the landfill. Moreover, considering the performance of the Clean Points' strategy in the year of study reported in Table 2, it is estimated that almost 30 new Clean Point facilities should be opened to obtain a result that would be far from the reduction objective of Law 13,592. Obviously, achieving a 100% effectiveness is almost impossible, and complementary qualitative research is needed to understand the will of the citizens in participating of these changes.

With respect to the second priority, when we estimated the flow associated to skips disposed in open dumps, we took a conservative 50/50 proportion of correct/incorrect disposal. However, as explained in Table 1, the increase of waste arriving through skips at the landfill was three times the superior limit of the 99% confidence interval of previous disposal registers. Therefore, it is possible that up to 17% of the total waste final-disposed is done incorrectly.

Despite these observations, it is important to signal that Tandil is one of the few cities of the province having a sanitary landfill (OPDS, 2019). As in many developing countries, especially from the Latin American and the Caribbean region (Brunner and Fellner, 2007; Diaz, 2017), the priority in the province is still the safe disposal of not valuable solid waste. This explains why the city is often regarded as an example of waste management by foreign and local authorities. At the same time, it arises questionings about the adequacy of the Law objectives formulation regarding the reduction of waste sent to disposal, which was too ambitious and too difficult to measure.

3.4.2. *Safe disposal and after-care free landfill*

Regarding open dumps, while some authors suggest a punishment approach to resolve this problem (Seror and Portnov, 2020), we believe that, for our study case, an analogic or digital tracking system for skips would resolve illegal dumping in a relatively easy way.

However, even if all the waste were disposed in the landfill, the absence of a properly waste separation-at-source strategy would make it impossible to get an after-care free waste landfill, which is considered an additional goal of integrated waste management (Allesch and Brunner, 2014).

The case of batteries in Tandil is illustrative. According to official statistics (MdT, 2019), 7 tons of discarded batteries were collected in 2017 through a special separation program. However, an average consumption of batteries of more than 1 kg/pers/year has been estimated for Argentina (Brailovsky, 2016). This means that, even if local statistics are correct, 95% of batteries of Tandil are either sent to final disposal (landfill or open dump) or are being stocked and will be discarded in the future. What is more, while the landfill was opened in 1998, the current program to divert batteries from the waste stream started in 2013.

This situation is worsened by the fact that the landfill collected leachate is sent to a treatment facility that does not work properly. From 10 years to now, the only function of the plant is to give a partial anaerobic and aerobic treatment to the leachate before its aspersion over the closed landfill modules (Landfill Responsible, personal communication). This reinforce the need of source separation.

Considering that the landfill in use is at the end of its life-cycle (less than 1 year to its closure), increased effectiveness in the divert of special waste from landfilled waste is imperative before the opening of a new one.

3.4.3. *Resource recovery*

Regarding the limits and performances of the strategies in place, several recommendations for improvement can be suggested, starting with the improvement of official statistics, which have demonstrated to be largely overestimated.

One of the most evident possible improvements is related to the valorisation of organic waste fraction, which represents more than half the waste generated at households (Villalba et al., 2020) and almost half the waste arriving to landfills in Argentina (ARS, 2012; Capparelli, 2019; The World Bank, 2015). Beyond the importance of reducing impacts and costs of landfilling waste, a composting strategy, for example, could allow for the recovery of a significant amount of nutrients available in biowaste (Zabaleta and Rodic, 2015).

Importantly, until recently, a resolution of the Sanitary and Agri-food Quality National Service (SENASA) prohibited the commercialization of compost produced from urban solid waste. However, a 2019 joint resolution by SENASA and the Environmental Control and Monitoring Office set a regulatory framework of compost production from urban waste. Additional incentives may be necessary, though. Scheinberg (2012) and Scheinberg et al. (2010) signal that for Mali, where more than 80% of this stream is recovered, it is the dry sahelian climate which motivates the agricultural value chain to "pull" the demand of compost. In Tandil, this demand is absent because the city is located in one of the most soil nutrient-rich regions of Argentina.

Regarding inorganic waste, promoting and boosting the IRS work has shown to be an adequate strategy in developing countries (Velis et al.,

2012) and is a key part of the ISWM framework (Wilson et al., 2015). The already high recovery performance of waste pickers in recovering board and paper from shops found through our analysis, however, raises concern about how much the IRS can improve it. The inclusion of new material categories to be recovered from shops, especially those not mainly generated in households, may be needed.

Moreover, a deeper analysis of available strategies for those inorganic waste categories that are not addressed today is needed. In the case of households, sanitary household waste (SHHW) and plastics other than PET and PEAD account for 18% of the total generated waste (Villalba et al., 2020). While in the first case reducing its generation may be difficult, the last is clearly related to packaging and may be reduced through a minimization strategy focused on this aspect. Importantly, this should be mainly addressed at a national and international level.

In the case of C&D waste managed through skips, it is possible to recover this fraction for reuse and, at the same time, it made little sense to use the scarce landfill capacity for it. A treatment step for this waste circuit may be adequate.

Overall, the challenge in the improvement of resource recovery will be to significantly increase the quantity of recovered materials while conserving an adequate quality (Stanisavljevic and Brunner, 2019).

4. Conclusion

Material flow analysis can provide a sound base for the development of indicators evaluating how a city performs regarding resource recovery and safe disposal, major components of ISWM.

Since recycling programs are generally focused on specific materials, waste composition data is crucial to estimate their recycling rates. When, in addition, recycling programs focus on specific waste sources (e.g., households), availability of waste composition data disaggregated at an adequate level is needed to properly assess the performance and find improvement paths of strategies in place. In developing countries, where waste pickers are often the main actor of resource recovery, estimating their contribution to final disposal reduction is imperative.

The general procedure followed in this article, along with the mass balance table and their related indicators, constitute an adaptable-to-case tool that can be used in other cities to analyse and find improvement opportunities for their waste management system.

Declaration of competing interest

The author declares no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2020.110453.

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Recent evolution of the informal recycling sector in Argentina within the 'popular economy': Measuring its impact through a case study in Tandil (Buenos Aires)

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Abstract

The integration of the informal recycling sector into formal waste management systems is imperative to the implementation of the circular economy in the Global South. In Argentina, after the 2001 crisis, some large cities such as Buenos Aires greatly improved their informal recycling sector integration. In medium-size cities from the rest of the province, this was not the case. However, the formation of a national coalition between different sectors of what is now called the 'popular economy' forced the enactment, in the context of a new crisis, of a Social Emergency Law, which includes a Complementary Social Salary equivalent to half the minimum wage, among its main features. In this paper, we recap these recent changes and we use the InteRa framework in a case study to measure how, along with academic and civil society support actions, they influenced the informal recycling sector integration in an intermediate city of Buenos Aires province. Our results show that the inclusion of the informal recycling sector improved rapidly after the availability of the Complementary Social Salary. Nevertheless, we registered a hard-to-overcome stagnation in some indicators of the InteRa framework, related to the weak engagement of the local municipal government with the informal recycling sector. Importantly, the advent of the Complementary Social Salary was not reflected in any indicator because there is no specific action related to this aspect in the InteRa framework. This may give an insight into future methodology improvement.

Keywords

Informal recycling sector, developing countries, popular economy, Argentina

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Introduction

Waste management (WM) is today considered a key component of the circular economy (European Commission, 2015) and an entry point for sustainable development (UNEP et al., 2015). At the same time, it is widely accepted that WM is mainly a regional and local issue subject to legal arrangements and political will, which needs adaptation to geographical characteristics, current environmental baselines (Brunner and Fellner, 2007), social and cultural specificities (Villalba et al., 2020), and resources and technology availability. Therefore, the goal of globalizing the circular economy (Geng et al., 2019) will depend on the development of well-contextualized sustainable waste management systems.

In the Global South, the transition to an integrated and sustainable waste management (ISWM; Risso Günther and Grimberg, 2006; UNEP et al., 2015) should be based on empowering and working with the informal recycling sector (IRS; Diaz, 2017; Gutberlet, 2010; Velis, 2017; Velis et al., 2012). The IRS has been defined as those 'individuals or enterprises who are involved in recycling and waste management activities but are not sponsored, financed, recognised, or allowed by the formal solid waste authorities, or who operate in violation of or in competition with formal authorities' (Scheinberg et al., 2010b: 4). Throughout the world, the IRS is composed of millions of waste pickers who are responsible for the relatively high recycling rates found in low- and middle-income countries (Scheinberg et al., 2010b; Wilson et al., 2012).

In the Latin America and the Caribbean (LAC) region, rapid urban growth, structural poverty and repeated economic crises have made waste picking a subsistence activity for an important number of people. The *Regional Evaluation on Urban Solid Waste Management in LAC* (Tello Espinoza et al., 2011) found a strong correlation between the poverty and indigence levels of countries and the number of waste pickers per inhabitant. The same correlation was found between the unemployment rate and the number of waste pickers per inhabitant, while it was also

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stated that during an economic crisis, the number of waste pickers grows quickly (AVINA, 2013; Tello Espinoza et al., 2011).

In Argentina, the 2001 crisis enlarged the IRS population and triggered profound transformations in its structure (see next section). While in large cities like Buenos Aires this resulted in advanced inclusion of the IRS (EIU, 2017; Schamber, 2012), this was not the case in intermediate cities. However, recent changes at the national level related to the conformation of an alliance of different sectors of what is called the 'popular economy' (Pérsico et al., 2017) are opening new opportunities for IRS integration in medium-sized cities.

Different methodologies to measure IRS integration in waste management systems exist (EIU, 2017; Velis et al., 2012). Among them, the InteRa framework (Velis et al., 2012) allows a simple and rapid evaluation of the interventions done or planned and their visualization.

Thus, the objectives of this study are to recap the recent evolution of the IRS as part of the 'popular economy' in Argentina and to evaluate, through the InteRa framework (Velis et al., 2012), how this has impacted, along with academic and civil society support actions, on the IRS integration of an intermediate city of Buenos Aires province.

In the next sections, we first briefly describe the recent evolution and current situation of the IRS in Argentina. Then, we describe the methods and the case study. Finally, we present and discuss the results of the study, before the concluding remarks.

Brief historical framework

Informal recycling has been present in Argentina since the 19th century (Schamber, 2010), as was the case, at that time, in other regions now considered developed (Velis et al., 2009). After running unregulated for a long time, the IRS activity was forbidden in Buenos Aires city during the last military dictatorship (1976–1982), when engineered landfills and the privatization of waste services were promoted (Schamber, 2010). Dispersed to peripheral municipalities, the IRS decreased its activity over the next decade, but reappeared in the 1990s, when unemployment started to grow (Schamber, 2010).

A turning point in the history of the Argentinian IRS took place in 2001, after an economic crash with numerous political and social consequences (Argentina had five presidents in two weeks). Indeed, the percentage of households under the poverty line in 2002 increased to 41.4% while the indigence level reached 18%. These factors, along with the devaluation of the Argentinian peso, which increased the price of recycling materials, favoured a sharp increase in the number of *cartoneros* (waste pickers) (Chronopoulos, 2006; Schamber, 2010), which grew – only in the 'Gran Buenos Aires' – from 25,000 to 40,000 (AVINA, 2013).

This period of rapid growth of informal recycling activity in Argentina coincided with and was followed by a period of institutionalization and networking of the waste picker organizations. The horizontal and regular contact already existing between waste picker cooperatives in Buenos Aires city (Fajn, 2002) and a series of events organized by government actors, universities and international institutions (Schamber, 2010) served as stepping stones for an improved IRS organization. Rapidly, coordinated efforts between these actors resulted in the repealing of the law that forbade the IRS activity and the enactment of a new one that recognized the *cartoneros*' job in 2002.

From the interaction between *cartoneros* and popular and neighbourhood assemblies that emerged during the 2001–2002 crisis, a heterogenic *cartonero* grass-roots movement was formed, with non-waste picker leaders (AVINA, 2013). An early action of this movement was the foundation of the Excluded Workers Movement (MTE). Developed upon the organization of the *cartoneros*' work, the MTE gradually extended its action boundaries to reach other sectors of what later would be called the 'popular economy' (PE) (Grabois and Pérsico, 2015). This concept is built on the basis of broader and pre-existing definitions (Coraggio, 1993, 2018) and refers to the activities of those productive units related to a subsistence economy, where: (a) means of production are detained, exploited and in many cases created by workers; (b) the workforce is the most important component of value creation; and (c) there is no business rationality nor accumulation logic (Grabois, 2016). It includes (Grabois and Pérsico, 2015) peasants, waste pickers, ambulant vendors, artisans, delivery men/women, labourers in recovered factories (i.e. a closed down factory re-opened by its workers), domestic workers and tailors, among others, but excludes wage employees and employers.

In 2011, after several years of economic growth and empowerment of trade unions (Fernández Mouján et al., 2018), the MTE and other associations founded the Confederation of the Popular Economy Workers (CTEP), a trade union for workers of the popular economy. From this moment onwards, the evolution of the IRS in Argentina can be better understood in the context of the popular economy struggle.

New crisis and new opportunities. In early 2016, through an innovative resolution (Grabois, 2016), the CTEP was legally recognized by the Argentinian government as a complementary trade union for non-dependent workers of the popular economy. This resolution had multiple implications, as it allowed the CTEP to represent the collective interests of these workers, to create its social care programme and to promote its inclusion in the pension system, among other benefits (Fernández Mouján et al., 2018).

In the context of a new economic crisis with similar causes to those of the 2001 crisis, the CTEP organized, by the end of 2016, important protest rallies, which led to the enactment of a Social Emergency Law. This law institutionalized two main tools: first, a Complementary Social Salary (CSS) for workers of the popular economy which included both organized and unorganized waste pickers, which was half the national minimum wage; and second, a National Register of Workers of the Popular Economy. At the end of 2018, 271,100 people received the CSS (ANSES, 2018).

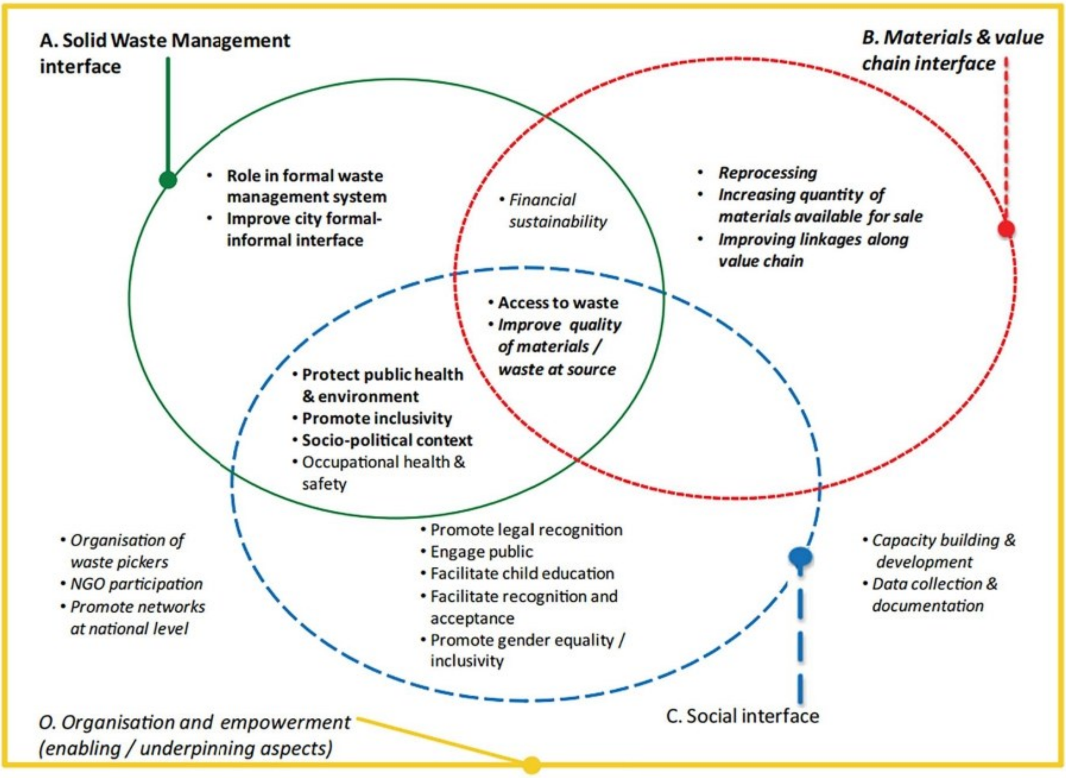

Figure 1. InteRa analytical framework and typology of interventions.
Source: Velis et al. (2012).

In what follows, we analyse how the evolution of the IRS situation in Argentina, along with the intervention of different actors accompanying the waste pickers organization after 2015 (see Results), allowed for important changes in the integration of the IRS into a medium-size city of Buenos Aires province, Tandil.

Materials and methods

The information we analyse in this case study was obtained as part of a transdisciplinary work started in 2014, in which scientific knowledge co-evolved with the IRS of Tandil. Throughout these years, we combined qualitative research methods, such as interviews or participative observation, with quantitative tools, such as material flow analysis (see Figure 4). To evaluate the evolution of the IRS integration presented here, we used the following specialized methodology.

The InteRa tool and framework

The *integration radar* or InteRa (Velis et al., 2012) is a tool used for the evaluation and improvement of the degree of integration of the IRS into the Solid Waste Management (SWM) system of a city. It is based on a conceptual framework that considers four categories of intervention to boost the IRS (see Figure 1). Three of them are based on the interfaces between the IRS and the 'outside world' (A: with the formal SWM system; B: within the value chain; and C: with society as a whole). A fourth category underpins the others by grouping actions that facilitate the fulfilment of interventions in the others (O: organization and empowerment).

Each interface groups several *intervention points*, i.e. key factors that can improve the role of waste pickers in the formal SWM system and/or improve their living conditions, which are evaluated by the degree of existence or consideration of some *specific actions* (SA) that should allow for the achievement of the *intervention point*.

InteRa translates the framework evaluation into four sustainability indicators by measuring the importance or consideration of each interface or *intervention category* in a case study. Each indicator is constructed by averaging the scores of its inner *intervention points*, which are calculated, in turn, as the arithmetic mean of *specific actions*' scoring. At this lower level, a qualitative assessment of each SA is translated into three possible numerical scores: (a) 1, if the SA is 'treated as a key action'; (b) 0.5, if the SA is 'considered to a medium degree'; and (c) 0, if the SA is ignored or if no information is available. Therefore, the intervention point score and the four main indicators are bounded between 0 and 1. Finally, the four main indicators are represented in a radar diagram.

The InteRa framework has been applied to 10 cities in Velis et al. (2012), in an illustrative manner, and to Sorocaba City in Brazil (Silva de Souza Lima and Mancini, 2017). Therefore, it is the first time that this methodology has been applied to an Argentinian city.

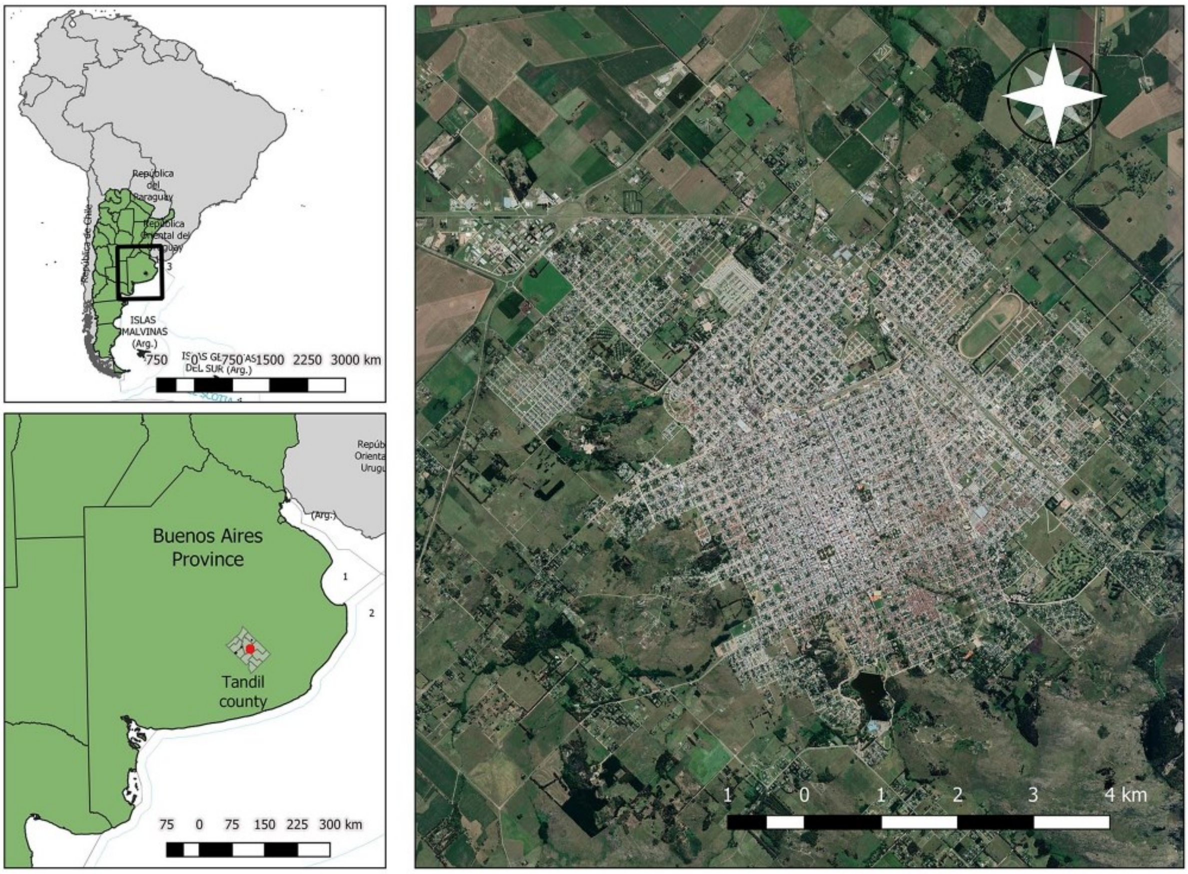

Figure 2. Study area. Buenos Aires province is shown in the black square on the upper-left panel and in the bottom-left panel, where the county of Tandil is presented with Tandil city in red. Tandil city is shown on the right.

Case study: The IRS of Tandil. Tandil is a city located in the south-east of Buenos Aires province (see Figure 2). With an urban area of 50 km^2 and 128,900 inhabitants (INDEC, 2015), the city follows a sprawl model of growth (Fernández and Ramos, 2013).

The presence of waste pickers in Tandil has been registered for decades. In 1995–1996, 77 waste pickers were recorded, who had no income other than from the commercialization of recovered materials (García, 1999). Before the construction of the first sanitary landfill in 1998, solid waste was disposed in an open dump where more than 30 waste pickers worked daily, and some families lived permanently.

As was the case for Buenos Aires city, the IRS of Tandil was, for a long time, ignored before being excluded. The construction of the first sanitary landfill clearly shows how this mechanism worked: the existence of waste pickers was denied by the authorities of the time (García, 1999); however, when they prepared the bidding for the construction and management of the sanitary landfill and the closure of the old open dump, they arranged for the ban on waste pickers to operate in both places (García, 1999).

Before the beginning of our investigation in 2015, no other register of the waste pickers' activity in Tandil could be found in our literature review. However, we learnt, through interviews with current *cartoneros* and key actors, that street waste pickers continued their activity and that, once the old open dump was closed, waste pickers avoided the private security of the landfill to recover materials, with the tacit acceptance of the municipal authorities and the private company.

In recent years, disregard of the IRS prevailed. In 2009, the Children Hospital Foundation started a plastic bottle recovery programme; the following year, the Taller Protegido (a non-profit organization aiming at the inclusion of people with disabilities) copied this strategy; and in 2013 an association for the care of children with rare diseases started a paper and board recovery campaign with the support of the municipality. These organizations never considered the involvement of the IRS in their projects. In the case of plastic, *cartoneros* did not collect it because local buyers would not want it, but paper and board constituted their main working material.

These aid-related recycling programmes were very successful, which pushed the municipality to open, in 2015, the first Clean Point, i.e. a facility where citizens could dispose of their recycling materials. Each material received was then destined for a different non-profit organization. These organizations also benefited from a free trip by train to Buenos Aires, which allowed them to sell the materials at better prices. Waste pickers were not

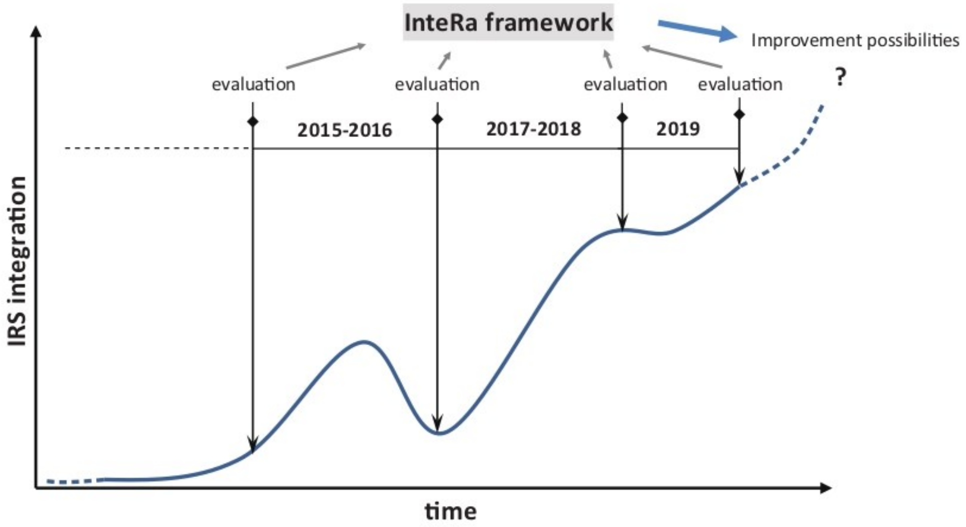

Figure 3. Phases of analysis and evaluation moments.
IRS: informal recycling sector.

considered in the Clean Point dynamic and were relegated to middlemen conditions.

Analysis phases and evaluation points

To analyse the impact of the changes in the IRS integration in Tandil and to explore possible future improvement paths, we defined four moments to apply the evaluation methodology: three of them in the past, i.e. an ex post analysis of each baseline situation (Velis et al., 2012), and one of them in the present, i.e. an a priori analysis, together with a search of means of improvement (Velis et al., 2012).

We started our work with the IRS of Tandil in 2015. Since the evolution of the IRS had ups and downs during the period of study, depending on where we started the baselines to run the evaluation, our results will differ. We can identify three distinct cycles of the IRS evolution: in the first cycle, some degree of IRS organization was achieved before an internal collapse; in the second one, the IRS was reorganized under the MTE orbit (see 'Brief historical framework'), followed by a rapid growth and major achievements; and in an ongoing third cycle, we can explore possible future paths.

We decided to situate baselines before our intervention, as well as at the beginning/end of each cycle followed by the IRS, as described in Figure 3.

Results and discussion

2015–2016: External support, cooperative formation, visibility and internal breakdown

In 2015, former members of an NGO, who were in contact with some street waste pickers, offered them help to establish a cooperative together. They asked for support from the local university, where our research centre had an incipient project on urban waste management.

While progress in the legal aspects advanced rapidly, the cooperative structure remained very weak, with only four waste picker and four non-waste picker members. They did not even have a working facility, just a temporarily conceded space at a 'recovered factory'. We therefore planned a university extension project (Arocena and Sutz, 2005); i.e. an action and territory-oriented project based on mutual learning and co-production of knowledge. The project involved prospective workers of the cooperative (waste pickers and non-waste pickers), students and researchers. Its main objective was to make the IRS role in WM visible through the implementation of a waste source-segregation experience in a neighbourhood of Tandil.

The pilot experience started with the co-designing of an information flyer by waste pickers and students, followed by its door-to-door delivery. The collection of a broad range of materials was performed by waste pickers and researchers. The programme was successful but ended abruptly for two main reasons: (a) the neighbourhood was near the cooperative headquarters but far from waste pickers' usual working routes; and (b) most collected materials (plastics and glass) were not bought in Tandil. Therefore, they were stocked for future sale, which not only was not compatible with their subsistence economy but also prevented the arrival of new waste pickers to the cooperative.

In late 2015, we organized a workshop with actors from the different recycling projects/organizations as well as the municipality. The objective of this workshop was to create a participative vision of the recycling sector of Tandil for 2030 through back-casting. Unfortunately, the Environment Department director missed the workshop, although she had confirmed her participation. For the remaining participants, her absence meant a lack of commitment of the local government with the issue at hand.

During 2016, the cooperative gained popularity through press appearances (e.g. El Eco de Tandil, 2016). The launching of

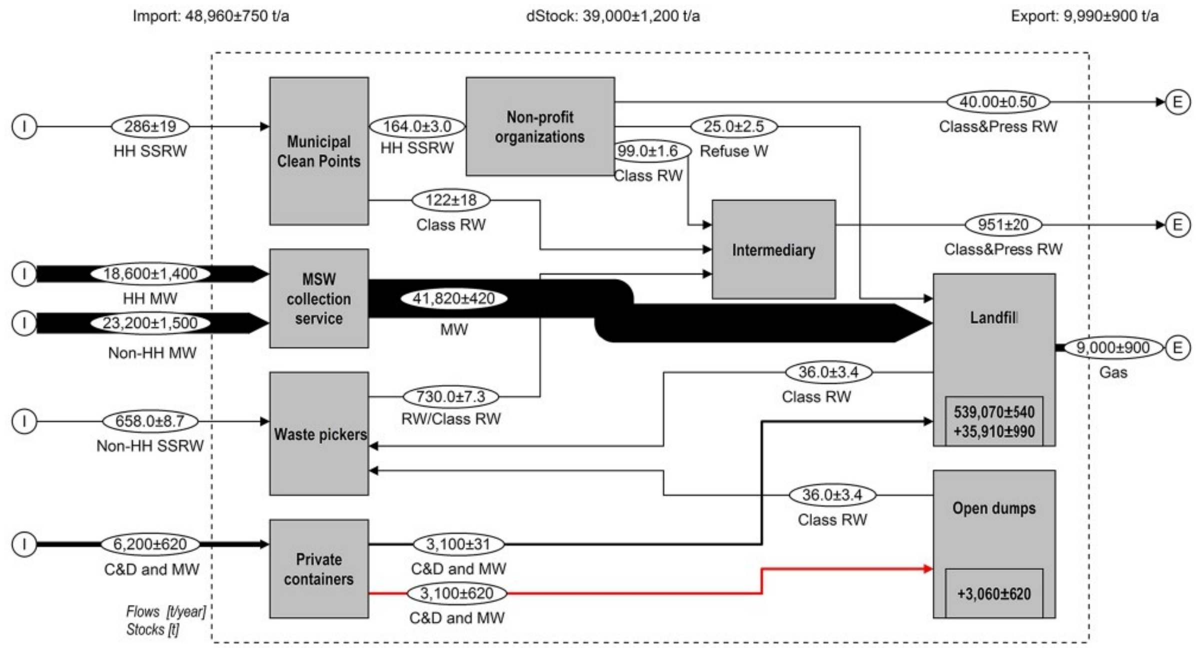

Figure 4. Waste flows in the solid waste system of Tandil for 2017.
Source: based on Villalba (2020).
HH SSRW: household source-separated recycling waste; HH MW: household mixed waste; RW: recycling waste; Class RW: classified recycling waste; Class&Press RW: classified and pressed recycling waste; C&D: construction and demolition waste; MW: mixed waste.

'Mesa GIRSU', a boundary organization (Guston, 2001) composed of elected councillors, the university, associations and informal actors, constituted a new pressure platform for IRS integration. Although the local government refused to participate at Mesa GIRSU, it agreed to have some meetings with cooperative representatives and, when the second municipal 'Clean Point' was launched, the municipality offered them its management. This offer was accepted but, unfortunately, the cooperative collapsed a short time later as a result of social conflicts between its members.

2017–2018: MTE connection and cooperative re-launching, IRS recovery indicators and CSS

Despite the establishment of its legal constitution, the cooperative was inactive for several months. Meanwhile, the 2015–2016 experience allowed us to finance a new and broader project under a cooperative promotion funding call. The objectives of this project were to analyse the possibilities of the IRS in Tandil based on a local WM system characterization (Villalba et al., 2020) and on IRS experiences in other cities of Argentina, mostly Buenos Aires.

A project member, who had travelled to Buenos Aires to visit MTE recycling cooperatives to gain knowledge on best practices, became the promoter of the cooperative's re-foundation, under the launching of the MTE Tandil. This confirms what Fernández Álvarez and Carenzo (2012) signalled for other action-research projects with IRS in Argentina; i.e. the existence of a permeable frontier between academia, NGOs and organizations under study.

As part of the new project, we performed a material flow analysis of the WM system for 2016, obtaining the first IRS recycling indicators (CINEA, 2017). These results showed that the IRS recovered much more material than the formal recycling circuit. This information was used by MTE authorities in many opportunities when demanding official support (see for example LOT, 2018). A detailed analysis – including uncertainty considerations – for 2017 is now available (Villalba, 2020), which estimates that the IRS recovered, without counting metal scraps, 1.7 ± 0.1% of solid waste generated, against 0.6 ± 0.07% through the municipal strategy (see also Figure 4).

The Complementary Social Salary (CSS) allowed for the incorporation of a large number of members to the cooperative. Moreover, it served to organize those waste pickers working on the sanitary landfill. The cooperative, with 24 inscriptions to the CSS in 2017, had 116 inscriptions at the end of 2018. However, not all of them effectively accessed the CSS and others were deregistered later (see Figure 5). In the first case, this was because some of them did not qualify for the CSS (e.g. they had official employment). In the second case, people were deregistered because they were not working as waste pickers or decided to stop this work. Figure 5 shows how the inscriptions to the CSS evolved and how many of these inscriptions are active today.

Another feature of the MTE connection and the CSS existence was the beginning of the *Promotoras Ambientales* (Environmental Promoters) programme in Tandil. In this programme, which was originally from Buenos Aires, recycler women raise awareness of the waste pickers' job, source separation and the importance of inclusive recycling, by visiting the city community door-to-door,

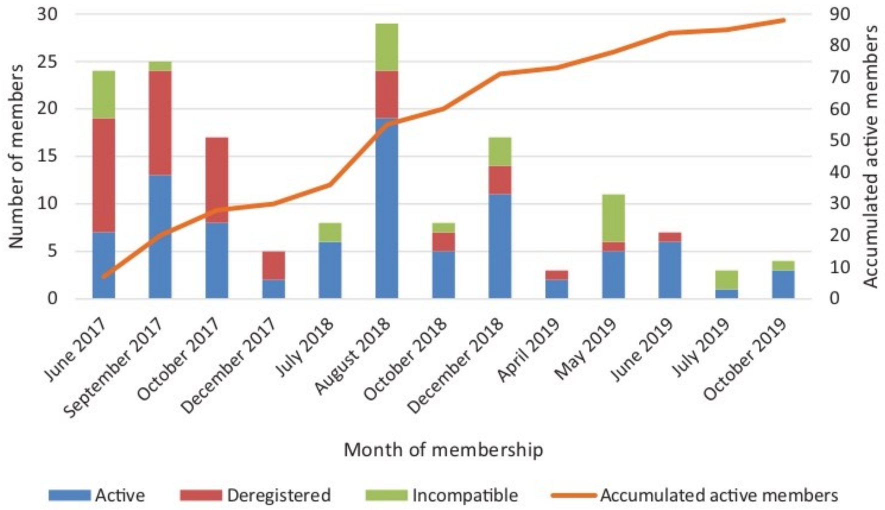

Figure 5. Evolution of the inscriptions to the CSS since its beginning and the current total number of active members.
Source: the author, based on the cooperative's registers.

while retrieving data about household members' predisposition to separate recycling materials.

After five months of a public campaign demanding that the local government provide a working shed, the authorities finally agreed to award a rent subsidy to the cooperative. Finding and conditioning the new place took several months. Moreover, the cooperative received no income apart from the rent subsidy because associated waste pickers needed to sell their materials day-by-day to middlemen and, to commercialize materials directly to industry, high stocks were needed. However, some materials such as plastic, which were not bought by intermediaries, started to be collected by waste pickers and stocked in the shed. This, along with materials furnished by citizens and some institutions, constituted the stock for the first sale (see next section). On the other hand, the local university contributed industrial scales and part of the electrical installation materials for the cooperative through different projects, among other support.

At the landfill, after a conflict managed in part by the MTE, an agreement was signed between authorities and waste pickers, providing them with an entry permit at specific times.

2019–: Recent advances and actual baseline

The conditioning of the shed constituted a plateau in the development of the cooperative. Once it was resolved in early 2019, the basis for important changes was established. This new period started with the acquisition of a multi-material compactor, which was possible thanks to the financial aid of the MTE.

Some months later, in July 2019, a first collective sale of more than 30 metric tonnes was made (see Figure 6). This sale allowed for the collection of enough funds to start paying, on a weekly basis, for the materials collected daily by some of its members, which was done at a much better price than they had with the middlemen. Moreover, as the prices obtained by the cooperative through the MTE in Buenos Aires are better than the prices obtained by local associations collecting recyclables, the cooperative started to commercialize most of the materials arriving at the municipal Clean Points. Also, a local enterprise started to buy HDPE from the cooperative. Figure 6 shows the amounts of recycling waste recovered by the waste pickers and commercialized through the cooperative in 2019. Importantly, this is only a fraction of the materials recovered by waste pickers, because most of them are still selling the materials daily to middlemen.

Today, the cooperative has 88 active members, of which 32 work in the landfill while the remaining work in the streets and the shed. They also managed to have a primary school running in the shed, as many members have not finished their elementary school studies.

A waste pickers' census is being performed with university support. At the same time, the Humanities School on campus started a source waste separating programme based on inclusive recycling which, in 2019, recovered 2 tonnes of recycling waste (mostly paper) for the cooperative (CRUT MTE, 2020). In the context of this project, the *Promotoras* are training students as well as faculty and staff.

InteRa results. Figure 7 shows the evaluation of the moments indicated in Figure 3 through the InteRa framework (see also supplementary information online). In the first baseline situation (2014), we observed advances in the organization and empowerment (O&E) and SWM Interface (SWM-I) indicators. The reasons for this positive result are the existing legal frameworks at province and national levels recognizing waste pickers and stating their inclusion in waste management plans; the existence of waste pickers' networks at a national level; the first NGO participation; and the IRS of Tandil non-dependency on external financing.

At the end of the first study period (2015–2016), little progress was measured in the O&E, which corresponds to the

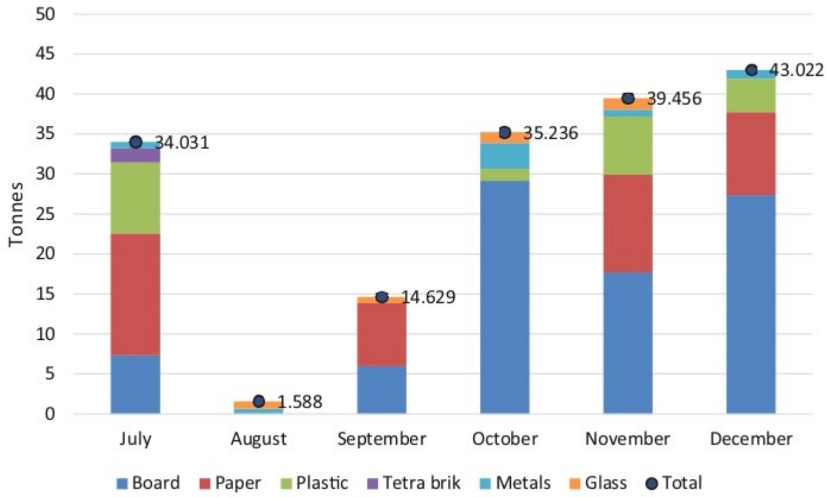

Figure 6. Metric tonnes of recycling materials recovered by the waste pickers and commercialized through the cooperative in 2019.
Source: CRUT MTE (2020), based on sell registers.

tentative cooperative organization and the participation of the university in a training course. The possibility of managing a new municipal Clean Point by the cooperative at the end of the period, public awareness and documentation of the IRS role by the university are responsible for the progress registered in the SWM-I. No progress was registered in the other two interfaces.

In the third period (2017–2018), qualitative changes were measured in most axes. These changes are mostly associated, on the one hand, with the MTE connection and the beginning of CSS and, on the other hand, with the strengthening of the university support. In the SWM-I, the higher visibility of the cooperative improved its acceptance and recognition by society and authorities alike, while new research stated the importance of the IRS in local material recovery. In the materials and value chain interface (M&VC-I), changes were very important and related to storage space availability, the expanded range of materials to be commercialized, better knowledge on how to segregate waste following the MTE instructions, and the direct contact with industries provided also by the MTE Buenos Aires.

The social interface (S-I) indicator, which had a value of zero for the earlier periods, reached the level of the other indicators. Again, the MTE underpinning provided know-how and recommendations related to internal work organization, the advancement of educational offers to cooperative members and the recognition of the IRS role through programmes such as the *Promotoras Ambientales*. Moreover, the recognition of the CTEP as a trade union followed by the CSS confirmed the recognition of waste picking as a profession.

Finally, the O&E indicator showed little progress in this period. In part, this corresponds to a reduction in the score of the financial viability intervention point, as the cooperative was dependent on the municipal subsidy to the shed rental at the end of the period. Also, this may be explained in part by the effort made during this period in the exploitation of the already existing potential, allowing for the progress on other aspects but

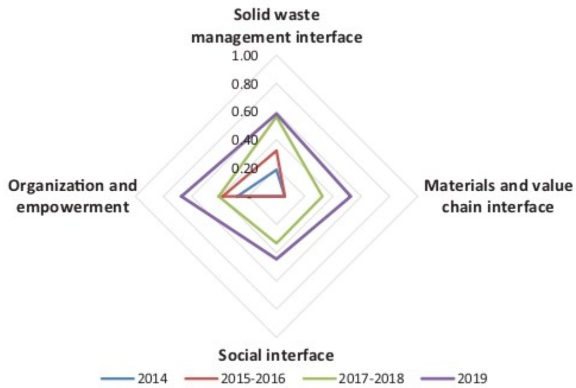

Figure 7. Evolution of the InteRa indicators during the phases of analysis.

inhibiting the development of new empowering actions. However, it is important to note that for the first time, a harmonic integration of the IRS was achieved, that is, similar in all axes in Figure 7, as recommended by Velis et al. (2012).

The last evaluation corresponds to the 2019 first semester. A stagnation in the SWM-I indicator can be seen, which may be due to an inherent limit in the progress of this indicator without the active participation of the municipality (see next section). In the M&VC-I, progress was possible thanks to the incorporation of the press to densify waste, to the contact with a local industry which started paying for HDPE collected by the cooperative and to the beginning of source segregation campaigns by self-organized citizens in some local neighbourhoods. In the S-I indicator, the improvement is related to the acquisition of uniforms, identification cards and safety equipment through the MTE. Finally, in the O&E, the first material sale to Buenos Aires, which improved the understanding of secondary raw material specifications, along with the recording of physical and monetary flows, marked a significant increase of the indicator. Importantly, this indicator is more sensitive to changes because it is composed of less specific sub-indicators of actions taken.

Future paths for IRS integration: Who is who in the InteRa framework. The analysis of this evolution seems to show that progress in the IRS integration is pulled by the organization and empowerment axis, as signalled by Velis et al. (2012). The new advantage in the O&E-I indicator in the last evaluation may therefore indicate that future improvements are possible. However, when analysing *who* promoted the specific actions considered or fully implemented (see supplementary information online), we can see that the local government is mainly absent or that, after many requests, it *conceded* some *benefits* but not *recognition*.

Regarding the SWM-I, room for improvement is largely conditioned by several factors. These factors are the willingness of the local government to grant the IRS full access to Clean Points and to better organize work at the landfill, and the advancement of a source-separated collection. Government involvement is needed because such an action cannot be organized by households or commerce and waste pickers only. In the M&VC-I, there are improvement opportunities related to the reprocessing of materials, where the cooperative can make some progress with the support of the university (see for example Carenzo, 2017). In other aspects, such as the organization of middlemen, municipal action is needed. In the S-I, most of the specific actions are 'considered to a medium degree'. However, when analysing *who* promoted these specific actions, we see that they are the result of the *Promotoras*' awareness actions, the MTE providing uniforms and other support, or the cooperative organizing a primary school for its members. Full implementation of these SA will most probably need local government intervention. In the O&E, there is still room for improvement in terms of capacity building through courses and the improvement of financial viability.

Finally, it is important to consider that in many specific actions, continual efforts for needs fulfilment, as well as support from the university in documenting and raising concern about the role of the IRS can all end when research programmes finish or change their focus. Consequently, the institutionalization of these measures may be important.

Conclusion

The integration of the waste pickers as part of the 'popular economy' and its main tool, the Complementary Social Salary (CSS), constitute a new milestone in the Argentinian IRS history. Although it is probably too early to fully evaluate the effects this instrument had in the IRS organization, the use of the InteRa framework allowed us to measure its beneficial impacts in Tandil city. Moreover, it permitted us to explore improvement paths and to identify progress obstacles.

One of the main issues to overcome is how to open and maintain communication channels with local authorities to co-design joint actions and integrated waste management policies. Replicating the national model of integration with other sectors of the popular economy may be an adequate strategy to address this challenge at the local level.

The InteRa framework could also be used to compare the CSS impact in other intermediate cities of Argentina. However, it is important to note that the CSS advent is not reflected in the O&E-I indicator because there is no specific action related to this aspect in the framework. This may give an insight into future methodology improvement.

More generally, further research may explore if alliances of self-employed sectors such as the Argentinian popular economy are desirable and/or possible in other countries of the Global South. These sectors, together with some often non-remunerated activities (e.g. care activities), cover most of the population's necessities. They can provide, therefore, the foundation of a new economic organization based on the full recognition of their work.

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Supplemental material

Supplemental material for this article is available online.

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