

## 論文の内容の要旨

論文題目      Municipal Solid Waste Management in rapidly urbanizing cities of the developing world: Exploring pathways to sustainability through a systems-based approach in Santa Cruz de la Sierra

(発展途上国の急速な都市化における固形廃棄物管理:サンタ・クルス・デ・ラ・シエラにおけるシステムベースアプローチを通じた持続可能性の考察)

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Municipal solid waste management (MSWM) is one of the major public services in cities around the world. For many cities in developing countries, MSWM is still a problematic issue, causing various negative sustainability impacts, especially in rapidly urbanizing cities.

Bolivia, and specifically Santa Cruz de la Sierra, its largest and most economically prosperous city, showcase the struggles of developing countries in improving the performance of their MSWM systems in contexts of rapid urbanization and limited resources. As in other developing countries, it is common for the national and local governments to directly copy solutions designed for industrialized countries, without adapting them to the local conditions, which usually leads to unwanted results. It has been recognized that the characteristics of developing countries increase the complexity of MSWM activities. Moreover, there is a frequent excessive focus on infrastructure elements, neglecting the social dimension of MSWM, which is particularly relevant for cities in the developing world. The use of transdisciplinary and systemic approaches has gained attention in recent years for the analysis of MSWM systems in developing countries, however few attempts of applying these concepts in specific case studies have been found in the literature. Regarding the transdisciplinary, special relevance has been attributed to the co-design and co-production with non-academic actors across the research process. Regarding the systems approaches, a balance

between “hard” systems and “soft” systems techniques has been recommended as a response to uncertainty and lack of data in developing countries context.

This research aims to analyze MSWM in Santa Cruz de la Sierra, a rapidly urbanizing city of Bolivia, from a multi-level and system-based perspective, in order to explore pathways influencing its sustainability. Specific objectives include to:

- 1) Understand the institutional context at the local and national levels, and unravel the sustainability transitions of MSWM system in the city;
- 2) Identify the variables and inter-linkages corresponding to the main sustainability impacts of the MSWM system in the city;
- 3) Determine the mechanisms and assess the main sustainability impacts of the current MSWM practices;
- 4) Explore the outcomes of the MSWM system under different scenarios of adoption of sustainable practices

Objective 1), analyses primary and secondary data through the lenses of the “Multi-Level Perspective on Sustainability Transitions” (MLP) and the “Integrated and Sustainable Solid Waste Management” framework (ISWM) in order to understand the transition of MSWM systems in the last decades at the national and local level. Secondary data consists of reports and statistics about solid waste management, sanitation, and urban planning. Primary data consists of 40 expert interviews with representatives of the institutions and organizations mostly involved in the MSWM system at both the national and local level.

Results indicate the unfolding of three overlapping transitions: (a) collection and centralized disposal; (b) environmentally controlled disposal; and (c) integrated solid waste management. These transitions had variable degrees of completion for each of the ISWM dimensions. At the city level, the rapid population and economic growth seem to have created pre-conditions for the third transition (i.e. formal and informal recycling activities). However, due to rapid and unplanned urban development the stabilization of the first and second transitions has been hindered. Major identified challenges include the inability of governments to respond adequately to the roles needed for each transition. This is often driven by issues associated with the incomplete decentralization process at the three government levels in Bolivia, politicians’ vested interests, and lack of political will to prioritize waste management issues.

For objective 2), a causal loop diagram of the MSWM system of Santa Cruz de la Sierra is developed. A draft was originally created by the researcher using primary and secondary information (from Objective 1), and the definite one

through two participatory modelling sessions with four experts, representing the local government, private sector, and civil society in Santa Cruz de la Sierra. The causal loop diagram elicited the mental models of stakeholders, identifying the main variables impacting the sustainability of the MSWM system, and their influencing mechanisms. At the macro level, stakeholders identified the political will and community awareness as factors influencing policies implementation and resource allocation. On the other side, main unsustainable practices identified related to household waste dumping and burning, while sustainable practices corresponded to household waste source separation, formal recovery, and informal recovery. Most of the issues and connections identified by the stakeholders related to household waste practices, which combined with the fact that household waste constitutes approximately 70% of the waste generated in the city, influenced in the selection of Household Waste as the focus of Objectives (3)-(4).

Objective 3) assessed most relevant practices affecting the sustainability of the MSWM system in Santa Cruz de la Sierra based on the results of Obj. 2: (a) household waste generation, (b) household solid waste management practices; (c) informal waste picking activities

First, the household waste generation determined generation rates, composition and factors influencing rates, through a household waste characterization study with 105 households stratified across income levels. The results indicate a median generation rate of around 0.51 kg/capita for low-income households, 0.59 kg/capita for medium income households, and 0.62 kg/capita for high income households, but the differences are not statistically significant across strata. When it comes to the components' analysis, differences across strata were found to be statistically significant for most of the components (i.e. organic, plastics, fine residue, sanitary waste). Results reflected characteristics of a rapidly developing city with organic waste accounting for around 50–70% for each of the strata, and fine residue accounting for around 10% in the estimation for the whole city and 15% for the low-income strata. For the whole city, the study estimates a median of 0.71 kg/capita and a mean of 0.55 kg/capita. Regarding the factors influencing rates, a multilinear regression analysis using a stepwise selection indicates that the number household members, household head education, presence of a kiosk in the house, and the proportion of children in the family are the most important factors influencing waste generation rates per capita.

Second, the assessment of household solid waste management practices estimated the prevalence of household waste dumping and burning, as well as source separation and recycling, and factors influencing these behaviors. A survey was applied to 305 households, including questions related to socio-demographic aspects, neighborhood characteristics, and questions using Likert scales to reflect different latent constructs for various behaviors related to

waste management practices (i.e. awareness, satisfaction, attitudes). The questions were analyzed through a combination of an exploratory factor analysis and structural equation modelling. Results indicate that negative practices (i.e. dumping and burning) are primarily influenced by household location, and in the case of dumping practices, additionally the satisfaction with the collection service, as the most influencing factor. Positive practices (i.e. source separation and recycling) seem to be mainly influenced by latent constructs such as concrete knowledge needed to conduct the separation, the attitude towards the practice, awareness of recycling positive impacts, satisfaction with the service and the knowledge about the local recycling context.

Third, the assessment of informal waste picking activities identified the characteristics (equipment, working hours, association membership), outcomes (i.e. income generation, amount of material recovered), and factors influencing this outcomes. To do that, 95 surveys conducted with informal waste pickers in various points of the city. Results indicate that the amount of material recovered is mainly influenced by the association membership followed by the use of transport equipment, while the income earnings are primarily affected by the use of equipment to prepare the material before selling, followed by the working hours and the association membership.

Objective 4) uses the general structure created in Obj. 2 to create a stocks and flows diagram and the results from Obj. 3 to populate the variables and improve their mechanism definition, in order to explore the future outcomes of the MSWM system in the next ten years under current practices and alternative scenarios based on key variables identified in Obj. 3. To explore the outcomes regarding burning and dumping practices, tested scenarios included the implementation of measures to control the unplanned growth and to increase the service satisfaction, showing that without measures to control this unplanned growth, rates of dumping and burning could double in the next 10 years. Regarding the recovery of recyclable material, results indicate that improving source separation and separate collection would significantly improve the formal recovery but reduce the informal recovery by more than 10% in the next years. Additionally, these improvements would not significantly reduce the amount of waste landfilled in the next 10 years. The results of the research highlight the importance of: a) Co-design and co-production of knowledge to address the sustainability of municipal solid waste management; b) Understanding and considering the interaction of MSWM activities with broader aspects, particularly societal and political dimensions; c) Considering the input from the community to adequately identify the factors influencing sustainable and unsustainable practices d) the use of a combination of hard and soft systems thinking approaches with participatory techniques for adequate policy design in developing countries.