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Characteristics of Riobamba's household solid waste generation and the benefits of source separation

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Abstract

The generation of urban waste represents a problem for cities, so quantifying and analyzing its generation is fundamental for municipal planning. To obtain these data, a study was conducted in Riobamba, forty households were selected, and data were collected, phase I determined the composition of the waste based on the quartering methodology, in phase II a pilot source separation program was implemented and quantified, with the data obtained estimates were made according to different percentages of recovery of materials compared to the extension of the useful life of the landfill. The result showed that the generation rate per capita was 0.71 kg/person/day, translated into about 200 tons of waste generated per day in Riobamba city. In terms of composition, the fraction of organic waste constitutes the largest proportion in the two phases with percentages of 60% and 73%, recyclables 20% and 12% and disposable 20% and 15%, which indicates that in the phase of separation at the source, the families created more awareness about the gen-eration of waste, so it is important to implement management practices to reduce the waste volume to a final disposal which will contribute to extend the useful landfill life up to 27 years.

1. Introduction

One of the objectives of the Sustainable Development Agenda 2030 is to "make cities more inclusive, safe, resilient, and sustainable", by lessen adverse environmental effects by 2030, with an emphasis on air quality and waste management [1].

In this context, cities around the world are concerned about waste, mostly because of the harm it does to public health and the environment. An excessive amount of solid waste produced, causes environmental pollution of soil, water and air [2] and is consid-ered a significant problem due to disposal issues like the decrease of available areas for the construction of sanitary landfills [3], so that municipal solid waste management (MSWM) has been top on the agenda in many gatherings [4] of multiple international events for sustainable development [5] growth of urban sanitation and waste manage-ment facilities is essential for reaching sustainable development targets by 2030 [6].

Thus knowledge of the quantity and composition of urban solid waste is essential for planning [7]. So it is that many countries have undertaken process of ordering and regulating solid waste through mechanisms such as MSWM Policy [3]. In general, the ac-curate design of the waste management strategies requires statistics and knowledge on waste generation and composition, that are among the most important factors to consider when selecting the most appropriate collection methods, treatment technology and final disposal [8], but unfortunately data are lacking in many developing countries [7,9,10]

The world is experiencing and environmental crisis, marked by excessive generation of waste, in particular household waste fed by consumerism and the effects of urbaniza-tion [11,12]. Its proposes problems for proper management, mainly due to the diversity of waste related to the consumption habits of the population, the scarce economic resources allocated for waste management and the lack of education and culture of the population, has caused the problem of comprehensive urban solid waste management [13].

Other problem that face some low development countries is the lack of mechanisms to help reduce generation, sorting at source and recycling so in their waste management system prevails under the final disposal scheme, where waste removal from urban centres and subsequent destruction of the waste were the only methods of MSWM [14], leaving behind the use, recycling and treatment of waste, as well as the final sanitary and envi-ronmentally adequate disposal [15].

The world's annual waste generation is actually 2.01 billion tons (33% of that is not managed in an environmentally safe manner) and is expected to increase to 3.40 billion tons in 2050 [16]. High-income countries generate about 34% of the world's waste, while the total quantity generated in low-income countries is expected to increase more than three times by 2050 [6]. In Ecuador, 12,671 tons of solid waste are produced daily and only 13.5% of this waste is collected in a differentiated way and recovered properly [17]. Mu-nicipalities have traditionally focused their efforts on solid waste management, through the elimination and destruction of solid waste in urban centres [14], so that a large amount of the waste generated is disposed of in landfills or cells without being recovered, recycled or reused. 50.5% of municipalities dispose of urban solid waste in landfills, 31.4% in Emerging Cells and 18.2% in dumps [17].

In this sense, since 1992, during the United Nations Conference on Environment and Development, governments are urged to consider aspects of the environmentally sound management of solid, industrial and municipal waste, recommending the implementa-tion of practices to reduce the generation of waste, increased recycling, reuse and disposal of waste in an environmentally safe way, in order to put the planet on the way to a safer and more sustainable future [18]. In 2021, the Circular Economy and Inclusive Recycling Law is published in Ecuador, which focuses mainly on protecting, recognizing, valuing, and promoting recycling and waste management mechanisms, with the aim of defining ecological criteria and mechanisms to promote the environmental management of waste and reduce its generation as a mechanism for economic well-being, creation of employ-ment sources and reduction of consumption of non-renewable resources.

The proposal of this study is to provide the municipality of Riobamba with inputs and information on the characterization of household urban solid waste to generate in-formation to promote sustainable actions on the comprehensive management of solid waste in the city of Riobamba and consider circular economy strategies framed the sepa-ration of waste at the source and inclusive recycling.

2. Materials and Methods

The data for this research was collected in a temporary period between January 3 and February 9, 2022, during two phases, analysis of the behaviour in the generation of waste (Phase I) and separation plan at the source (Phase II) at Los Alamos neighbourhood of Riobamba city, to collect data to analyse the generation, composition, and predisposition of source waste separation

2.1. Case study area

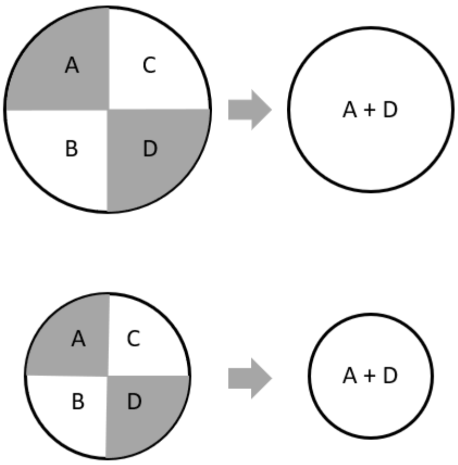
Riobamba is in the central highland region of Ecuador at 2,754 meters above sea lev-el, it is the capital of the province of Chimborazo and has an area of 2,823 hectares. Due to its location, it becomes the connection zone between the other geographical regions of the country. Riobamba has a population of 225,741 inhabitants, from which 70% live in urban areas and 30% in rural areas, with a population density of 2654 km2/hab. Its main eco-nomic activity is agricultural production in rural areas and commerce in urban areas [19].

2.2. Sampling technique, data collection and determination of generation and waste composi-tion.

For the selection of the study and sample population, a discriminative research was carried out based on direct observation of neighbourhoods that meet the inclusion criteria: be a residential neighbourhood; close to the city centre for logistics and execution facility of the pilot study; have base recyclers to seek their participation in the project, safety in the neighbourhood and finally that a previous work of edu-communication has been carried out so that, they have knowledge about waste separation at the source. A statistical pro-cedure was used to determine the number of samples to be analysed and obtain results with reasonable precision. In this sense, the sample size was determined using the for-mula for sampling a proportional population, obtained with the Q sample calculator with an expected error of 10% and 85% reliability, determining a sample size (n = 40) from a universe of 169 households [20].

To determine the characterization of the generation of waste, the 40 homes were se-lected randomly, with which a socialization was carried out to explain the objective of the investigation, schedules, and requirements for the collection of waste in the selected homes, during this stage. Eight oxo-biodegradable black plastic bags were delivered, so that the research participants could deposit their solid waste from their homes. The mate-rial collected daily was taken to the Porlón sanitary landfill and placed in a covered area. Once the solid waste collection process was completed, they were quartered using the fol-lowing methodology [21].

Figure 1. Quartering methodology



Two complete quadrants were extracted, seeing that, the sample was not managea-ble, a quartering was made again as indicated in figure 1. Subsequently, the waste was separated, based on its physical properties: organic, disposable, paper and cardboard, plastics, textiles, metals, styrofoam and tetrapack and subsequently the weight was determined by gravimetry [22]. Per capita production was determined using the following equation [21].

$$Per\ capita\ production\ (PPC) = \frac{Total\ amount\ collected (Kg/\text{day})}{Total\ \text{population served (in}habitans/day)}$$

Where, the total amount of waste collected was determined by adding the weights generated each day divided by the total population served determined by adding the number of members in each family

In (Phase II), the pilot plan for waste separation at the source was implemented, which lasted four weeks, its objective was to promote and analyse the levels of predisposi-tion for waste separation in the selected homes, for which separation kits, made up of: oxo-biodegradable plastic bags of different colours so that participants can separate waste, organic (green bags), recyclable (blue) and disposable (black), in accordance with Ecuado-rian regulations on the standardization of colours for deposit containers and temporary storage of solid waste [23]. The level of predisposition was analysed considering the number of deliveries made by each participating family in the two phases.

Finally, with the results obtained during phase I and II, the amount of waste that en-ters to Porlón landfill with respect to its useful life was determined, in addition, 6 scenari-os were proposed regarding the amount of solid waste that enters daily and the extension of the useful life of filling [24].

Table 1. Variables for determining the maximum capacity of Porlón landfill.

Variable	Considerations
Useful life of landfill	Starting: 2015 Fin: 2026
Production Per Capita	2015 – 2021: 0,6 Kg/person/day
	2022 – onwards: a value of 0.74 kg/person/day was used and the PPP was calculated for the rest of the years with a growth rate of 0.5% corresponding to small or simple populations.
Population	2015 – 2020: projections proposed by INEC
	2021 – onwards: the population growth rate is established using equation 4.Pf=Po*(1+r)t
Maximum load capacity of the landfill	The maximum amount in weight that the landfill can store was determined by adding the amount that has entered and will enter the landfill from 2015 to 2026, due to the lack of volumetric data provided by the GAD.

The data used were provided by the municipality. Table 1 establishes the variables used to determine the maximum load capacity of the landfill.

The proposed scenarios consist of reducing the amount of waste entering the landfill, respecting to the characterization carried out in this project and based on other assump-tions. To obtain the values in different scenarios, the annual production was determined with the respective decrease of each scenario. In other words, in scenario 2 it is expected that only 80% of the waste produced annually enters the landfill. Therefore, the produc-tion of each year was multiplied by 0.8. Subsequently, the production of waste was added from 2015 to the year in which an approximate value is obtained to the total load of the landfill. In the second scenario, the maximum capacity of the landfill is reached in 2027, that is, the life of the landfill is extended by 1 year. This process was replicated to the rest of the scenarios, determining a different value for each one.

3. Results

The results show that the level of participation in phase I (Behaviour in the Genera-tion of Waste) was 75% that delivered the waste between 4 and 7 days and in phase II (Separation at the Source) it was 73%, which indicates there was an adequate level of par-ticipation allowing obtaining the necessary weights for the study, as well as, showing that there is a high level of predisposition and response of citizens to implement projects and pilot plans related to comprehensive waste management.

During phase I, the implemented methodology allowed obtaining adequate samples of solid waste to determine the per capita production and the composition of the materials generated by the population of a standard neighbourhood in Riobamba city. For this pur-pose, the users of the selected welling's were instructed to deliver the waste in accordance with the storage and management practices that each household carries out on a daily ba-sis to dispose of it in the containers, it was also evidenced that all the selected families do not classify at the source or have recycling practices, with these data was proceeded to count the weights and the number of participating families.

Table 2. Summary of results of urban solid waste generation – Los Álamos neighbourhood – First Phase.

Day of collecting	Number of inhabitants	Waste quantity (Kg/day)	PPC (Kg/inhab/day)
D1	85	89.43	1.05
D2	95	68.34	0.71
D3	93	55.13	0.59

D4	119	90.37	0.75
D5	105	47.98	0.45
D6	44	30.59	0.69
D7	64	43.22	0.67
Production Per capita (PPC)			0.71

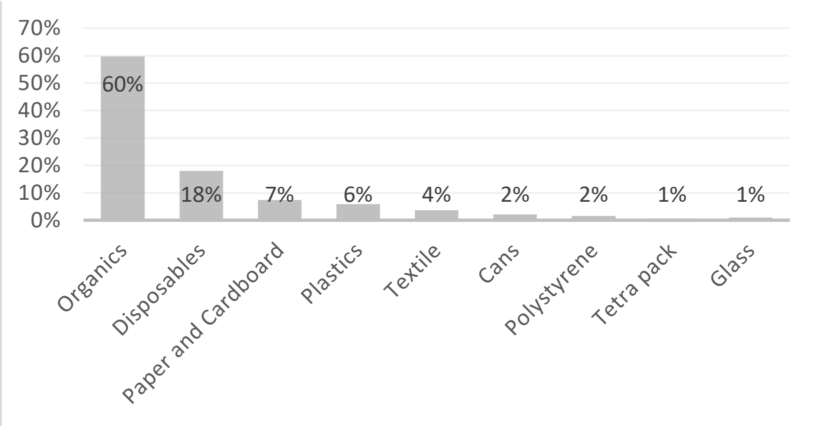
Table 2 shows the amount of waste generated, collected, and weighed per day, ac-cording to the day of waste generation can be seen that not all families delivered the waste daily and the weights vary from day to day. Therefore, to obtain the value of generation per capita, an average was made in which a value of 0.71 kg/person/day was obtained. The total waste collected in this phase reached 425.05 Kg, weight with which the total quartering was carried out with a control sampling, obtaining the following results.

Table 3. Composition of urban solid waste generation Neighbourhood Los Álamos – First Phase

Type of waste	Quarter Weight Total	Percentage Quarter Total	Quarter Weigh Control	Percentage Quarter Control
Organics	63.525	60%	32.1	58%
Disposable (others)	19.175	19%	10.1	18%
Paper and paperboard	7.892	7%	2.37	4%
Plastics	6.232	6%	5.33	10%
Textile	3.920	4%	2.08	4%
Cans and metals	2.295	2%	1.18	2%
Polystyrene	1.622	2%	0.89	2%
Tratra pack	0.6475	1%	0.59	1%
Glass	1.07	1%	0.29	1%
Total	106.38	100%	54.93	100%

Table 3 shows the behavior of urban solid waste from Los Álamos neighborhood during phase I. The composition of different types of waste is evidenced both in total and in the control quartering, obtaining as results percentages that corroborate the robustness of information collected and the results obtained.

Figure 3. Composition of urban solid waste generation in Los Álamos neighborhood – First Phase.



The analysis of the composition of urban solid waste collected during the first phase (figure 3) indicates that 60% is organic; 18% is disposable, plus 2% is polystyrene, which is a type of expanded polyethylene and whose composition cannot be recycled or is cur-rently not recycled in the country; Finally, the remaining 20% corresponds to recyclable materials such as plastics, paper and cardboard, glass, among others.

During the second phase, the participating households were subjected to an educa-tion program for separation at the source and participation and separation were motivat-ed in the following weeks, the program consisted of the delivery of colored covers, delivery of educational material to learn about the days and hours of collection of organic materi-als (Monday, Wednesday and Friday) and disposable and recyclable Saturdays. The waste was collected and weighed during collection at each address and the following re-sults were obtained.

Table 4. Summary of the composition of waste in the Los Alamos neighborhood – Second Phase

Waste Composition	Percentage
Organics	73 %
Recyclable	12 %
Disposable	15%

Table 4 shows the composition of waste by class during the second phase, thus, dur-ing the 4 weeks of differentiated collection, 73% of the waste corresponds to organic, 12% recyclable and 15% disposable.

In this phase the percentage of organic increase from 60% to 73% and the percentage of recyclables also decreased to 12% due to the fact that much of the material was deliv-ered to base recyclers or was used by the neighbourhoods' families and this waste was not delivered and was not accounted for.

In the same way, the percentage of unacceptable waste decreased to 15%, this hap-pens mainly because by separating the waste, a greater amount of organic and recyclable material can be recovered, since it is not mixed with other waste such as disposable. In this way, it is observed that the waste separation pilot plan provided favourable results, considering the decrease in recovered disposable waste.

This decrease is mainly due to the fact that the waste, when classified, is more likely to be recovered, some of the recovered wastes are either reutilized at the source within the same families or sold to recyclers, locally known as recicladores de base (persons who practice the exchange of recycled waste for other goods) [25].

In the same way, it is observed that in composition in the second phase the genera-tion of organic waste slightly increased and the number of disposables and disposables decreased, which can mention that by classifying the waste it is avoided that organic and recyclable material is lost and it is consider as disposable.

Comparing the weights obtained during the Phase I and Phase II study, the follow-ing weights were obtained.

Figure 4. Weights of waste collected per week – Los Alamos

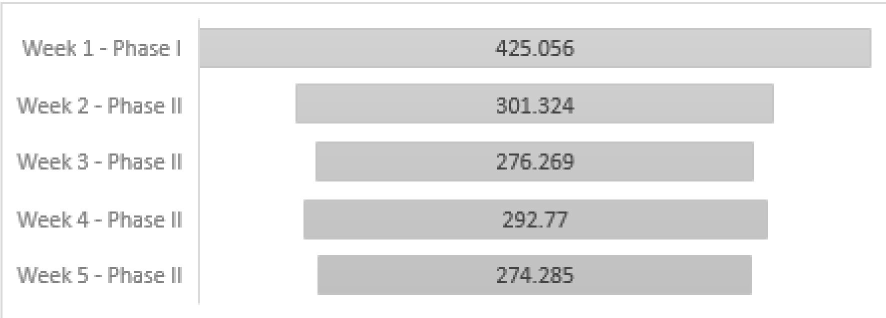


Figure 4 shows a decrease in weights collected when comparing phase I with phase II, which maintain an average of 286.16 kg of waste.

Figure 5. Quartering methodology application at Porlón landfill.

Once phase I and II of the project were completed, the load capacity of the Porlón landfill was determined with the variables established in table 1, obtaining the values presented in table 5, and a maximum capacity of 774,342 tons of waste. for a period of 11 years (2015 – 2026). This scenario is proposed considering that there is no separation of waste at the source in the city and that waste recovery is minimal.

Table 5. Estimation of the load capacity in weight of Porlón landfill

Year	Population	PPC (kg/inhab/day)	Kg/day	ton/day	ton/ month	ton/yea r
2015	249891	0,6	149935	150	4498	54726
2016	252865	0,6	151719	152	4552	55377
2017	255766	0,6	153460	153	4604	56013
2018	258597	0,6	155158	155	4655	56633
2019	261360	0,6	156816	157	4704	57238
2020	264048	0,6	158429	158	4753	57827
2021	267238	0,6	160343	160	4810	58525
2022	270466	0,74	200145	200	6004	73053
2023	273734	0,74	203576	204	6107	74305
2024	277041	0,75	207065	207	6212	75579
2025	280388	0,75	210615	211	6318	76874
2026	283775	0,75	214225	214	6427	78192
Total capacity in weight of the landfill until 2026 (ton) 774342						774342

Given this situation, scenarios were proposed the amount of waste entering the land-fill be reduced, mainly by separating solid waste in homes and using it through activities based on circular economy.

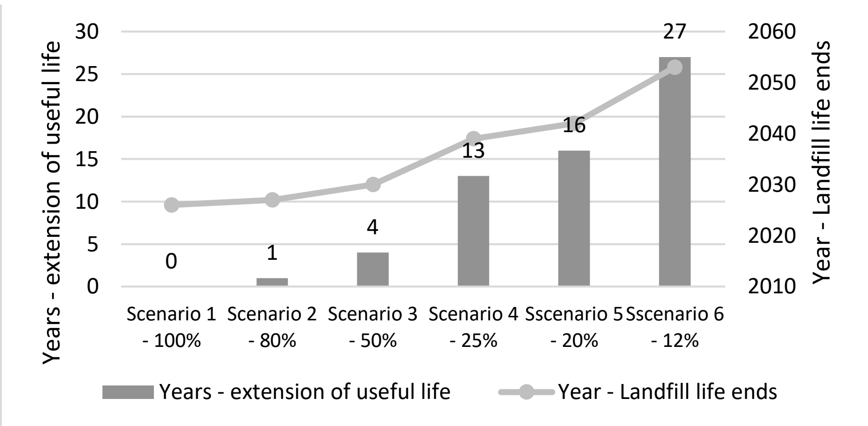
The scenarios, considering the population growth can be maintained, the increase in per capita waste production, as well as, the implementation of waste separation strategies and programs at the source, in addition to recovering a percentage according to the scenarios proposed from the year 2022 (table 6).

Table 6. Scenarios for the reduction of urban solid waste entering the Porlón landfill

Scenario	Description
1	Enter 100% of waste as currently happens, there is no separation at source, use of organic and recyclable.
2	Enter 80% of waste corresponding to organic and disposable according to this study, the remaining 20% (recyclable waste) are recovered.
3	Enter 50% of waste corresponding to disposables and a fraction of organic according to this study. The remaining 50% (organic and recyclable fraction) are recovered and used.
4	Enter 25% of waste corresponding to disposable and a small fraction of organic according to this study. The remaining 75% (organic and recyclable fraction) are recovered and used
5	Enter 20% of waste corresponding to disposable waste reported in this study. The remaining 80% (organic and recyclable) are recovered and used 100%.
6	Enter 12%, corresponding to the fraction of disposable waste in the event that there is an adequate separation of waste. The remaining material is used and recovered.

Once the projections were made and the scenarios determined, the values for each of them were obtained. This is how, if waste management continues without any type of waste separation program at the source and without any form of waste utilization, the useful life of the landfill will be until the year 2026. This contrasts with the information provided in Figure 5, detailing the increase in landfill life as less waste enters the landfill.

Figure 5. Scenarios of landfill useful life extension



If programs and/or pilot plans for separation at the source are implemented, it would be possible to extend the useful life of the landfill by one year if 80% of waste is entered, 4 years if 50% is entered, 13 years if 25%, 16 years if 20% enters and 27 years if 12% of the waste enters, so recycling can help diversion of Municipal Solid Waste from overstressed public landfills extending their operation life [26].

4. Discussion

This study reveals that in the city of Riobamba a standard neighbourhood generate has 0.71 kg/person/day of waste, the generation of urban solid waste is closely related to the number of inhabitants and the socio-economic factors particularly household size and income of a particular area [27,28], in this case the per capita production is similar to commercial, industrial and tourist cities in Ecuador [29], other studies show that the so-cio-economic conditions of the population directly influence waste generation [10], mainly due factors like gross domestic product in developing countries or the impact of the tour-ism among others [30]. Several authors mention there is a trend in the PPC of household waste, being higher in high socioeconomic extracts, which indicates the upper classes with higher consumption tend to generate more waste [31]. The residues also differ in composition [32-34], so that households having low income have a high percentage of or-ganic matter, and household having middle- and high-income households the percentage of organics is decreasing and the percentage of waste like paper, plastic, glass, and metal fractions increase in the waste, this pattern in the waste composition is attributed to high spending among better-off people on packaging materials and much disposed [35].

This trend of consumption and generation of waste is aggravated since the popula-tion is exposed to the introduction of new consumer products with a limited useful life and scheduled expiration [36].

However, in this study with proper separation at the source, differentiated collection and proper management the high percentage of organic waste could be managed and used to produce compost and other derivatives, since it is a practice widely accepted as sustainable and used in all systems associated with climate-smart agriculture, since it combines the protection of the environment with sustainable agricultural production [37].

Also since Riobmaba's main source of income is the production and commercializa-tion of agricultural products, such as potatoes, quinoa, broad beans, barley, kidney toma-toes, beans, peas, corn, among others, organic material could help improve the quality of the soils that is poor in all over the canton [38].

The recycle waste generated also can be recovered and returned to the production chain through circular economy strategies and can be managed by including grassroots recyclers in order to reinforce collection logistics of the city and promote the development of this vulnerable sector, in addition to the fact that these can be recovered by the grass-roots recyclers of the association of recyclers Manos que Limpian (ASOMALIM); who work under extreme conditions of risk and unhealthiest without state support.

The information gathered in this study shows that the sanitary landfill receives about 200 tons of waste per day, but does not have all the appropriate environmental conditions for waste management because there is no good leachate management, no adequate con-trol of odours, rodents and pests, mainly due to poor public management, in this context the results have shown that the best scenario is to increase any percentage of recovery thought improving waste management to increase landfill useful life, however, in several countries, llandfills are still the main means of household waste disposal [6], and spend between 20 and 49% of municipal revenues on waste, this amount is often unable to keep pace with the magnitude of waste generation [39].

Although municipalities have the responsibility to design and implement selective collection systems at source and recycling practices, many of them shown limited capa-bilities for improving sortation of waste from winding up as rejects in public overloaded landfills or leaked as littering into the environment [26]. Also, because land is scarce, hu-man settlements encroach on landfill space and, in some cases, local governments en-courage the construction of new buildings directly on top of operating or recently closed landfills [4].

5. Conclusions

This study reveals that Riobamba's per capita generation in an upper-middle income neighborhood generates 0.71 kg/inhabitant/day of waste, an average per capita production similar to that of other cities with high economic growth, suggesting that Riobamba is a growing city with higher purchasing power. The organic fraction is the highest with a flow of between 60% and 73% depending on the management practices and separation of waste at the source, indicating that while separation practices improve, a higher percent-age of organic and recyclable waste can be recovered and could be used as raw material for other processes.

The results also indicate a high percentage in the level of predisposition of citizens for the waste separation at source, for this reason, the application of waste management pro-grams like recycle or source separation would considerable acceptance, which is why the Municipally is urged to maintain the source separation programs in Los Alamos and ex-pand to other neighbourhoods.

If the waste separation is promoted on a large scale, adequate conditions would be presented for the use and recovery of recyclable and organic waste, through practices based on circular economy. This will generate social, environmental and economic bene-fits for the citizens and municipally.

Separation at source plans would increase the use of waste in circular economy, the useful life of the city's sanitary landfill will be extended up to in 27 years if only the frac-tion of waste considered disposable would be located in the landfill, for which it is neces-sary that public policies be implemented from the competent agencies aimed at improving the solid waste management system and inclusion of base recyclers in these processes.

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