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30th CIRP Life Cycle Engineering Conference.

Formalization of recyclable waste transfer stations within the Grand Guayaquil

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Abstract

Ecuador is a country in which only a third of the municipalities classify their waste before it is collected by garbage collection services. The country generates 4.06 million metric tons of waste each year, which is constituted of 62% of organic, 25% of recyclable and 13% are of another type of wastes. Of this total, only 4% is recycled, diminishing the space for landfills and increasing the cost of solid waste management. For this reason, the need for urban solid waste recycling systems has become very important. A waste transfer station is an important component of a waste management system and functions as a link between a community's solid waste collection program and the final waste disposition. The study area was Grand Guayaquil which is the conglomeration of Guayaquil city and its closed neighbor surrounding cities (Duran, Samborondon, and Daule) from the province of Guayas in Ecuador, where waste transfer stations are used to temporarily store, and classify nonhazardous recyclable waste, sold by informal waste pickers, for after commercialization to recycling facilities. The main objective of this paper was to gain more insights into the geo-location of waste transfer stations, together with the quantification and characterization of recyclable waste they store for further reselling in five different cities of the province of Guayas, Ecuador. By knowing the location of these waste transfer stations and the types of recyclable materials they accept, future research can design a reverse logistic system which includes the informal collection sector.

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Keywords: waste transfer stations; Guayas; GIS; suppliers; buyers; recyclable waste

1. Introduction

The world is experiencing an environmental crisis, marked by the excessive production of waste, in particular, household waste fed by capitalism, consumerism, and the effects of rapid urbanization. However, 0.9 billion people still lack access to

regular waste services in urban areas worldwide, particularly for low-and-middle-income countries [1], such as Ecuador.

According to the World International Bank, the country has a total population of approximately 16.8 million people and a gross domestic product per capita of \$5,920 [2]. The administrative structure includes the central Government, 24

provincial administrations, 221 municipalities, and 1,149 parishes with their own political, economic, and administrative autonomy. The Ecuadorian National Institute of Statistics and Census (INEC, from the Spanish acronyms), states that every Ecuadorian produces, on average, 0.58 kg of residues per day [3]. At the national level of the total waste generated, 96% is buried in various final disposal systems, while 4% is recovered by informal waste pickers (recyclers), mostly impoverished women who work in precarious conditions [4]. According to the information declared by the municipal decentralized autonomous governments (MDAG), 48.2% of municipalities dispose of urban solid waste in sanitary landfills and 51.8% in open dumps.

In this context, leveraging the urban mining ecosystem through the informal waste collection of recyclable materials can help decrease the amount of waste sent to landfills [5]. Like India or Vietnam [5-6], the informal waste collection of recyclable materials occurs as shown in Figure 1 for the country. The current waste streams, collection, and disposal mechanisms in Ecuador involve various stakeholders from both the formal and informal sectors. Domestic waste is not typically source-separated meaning tradeable, recyclable waste is mixed with organic waste and other contaminants. Typically, this waste is curbside in front of the business or household directly for collection or placed at a designated dumpsite. Due to economic interests, the most collected materials by informal waste pickers (IWPs), or level 0, are plastic, glass, metal, and paper [7].

Next, the IWPs bring their collected yield to an aggregator, typically referred to as a collection center or junk shops, or waste transfer stations (WTSs). These WTSs are referred to as L1 aggregators and typically interact directly with L0 however some buy directly from businesses or are pickers themselves. These stations are the first point of tradeable consolidation in the waste value chain. In Ecuador, particularly in Guayas province, transfer stations can vary greatly in size, infrastructure and setup depending on an expansive range of factors. Generally speaking, L1 aggregators have simple infrastructure in place, trade with IWPs and are family-owned businesses.

Moving along the value chain, L1 aggregators consolidate tradeable waste streams, and once a particular volume is reached (usually restricted by transport or storage capacity) they have two options: (1) trade with L2 aggregators or consolidation centers, which are much larger in size, trading bigger volumes of waste and are operating larger, more established businesses, and can offer additional services such as prewashing the collected waste or (2) sell directly to other traders, end-buyers, or L3 recycling facilities. The main distinguishing feature between the two levels is the size. While some L1 aggregators trade directly with buyers, often L2 consolidators are in between as they collect more volume and own trucks for transportation before selling to other traders, end buyers or L3 (e.g., factories). Besides the informal waste collection system in Ecuador, municipal waste operators are responsible for the collection and transport of waste to landfill. Typically, households and businesses will leave their waste in front of their homes for municipal workers to collect. Generally, the waste would have been

already scavenged by L0 IWPs before municipal workers reach the waste and if there are any remaining tradeable, they will be buried with the rest of the waste, due to the lack of separators at the local landfill.

Within the informal recycling business, WTSs emerge as sustainable alternatives to optimize the collection, sorting, and transportation phases of recyclable waste. A WTS is a technically established place to allow non-hazardous recyclable waste and temporary storage before transportation to other bigger L2 consolidation centers or L3 recycling facilities. A waste transfer station is an important component of a waste management system and functions as a link between a community's solid waste collection program and a final waste management system. Transfer stations have been used for diverting, collecting, and transporting recyclables as well as incorporating materials processing systems into the same facility [8]. Using WTSs present several advantages: (i) establishing a market for curbside L0 collectors to sell their products, (ii) allowing them to accumulate more of each type of recyclable waste before sending them to L2 or L3 facilities (normally, the recycling facilities don't accept little volumes, as the ones delivered by IWPs), (iii) maximizing the total recycling rates (one established, this L1 stations can receive waste not only from L0 scavengers, but by all the near community, increasing the yield rates), (iv) reducing the harmful environmental impacts on residential areas, and (v) improving the transportation efficiency by reducing the number of trips to the recycling facilities. However, little is known about these centers and the types and amounts of recyclable waste they handle. They remain a virgin field for circular economy integration in third-world developing countries.

One first step to improve the current informal recyclable waste collection is to geo-locate the waste transfer stations and obtain important data on the volumes of waste they receive and resell. Geographical Information System (GIS) can help to identify the spatial distribution of these WTSs. Through GIS, a great amount of data can be efficiently stored, geo-referenced, retrieved, used, and displayed, in relation to user-defined specifications [9].

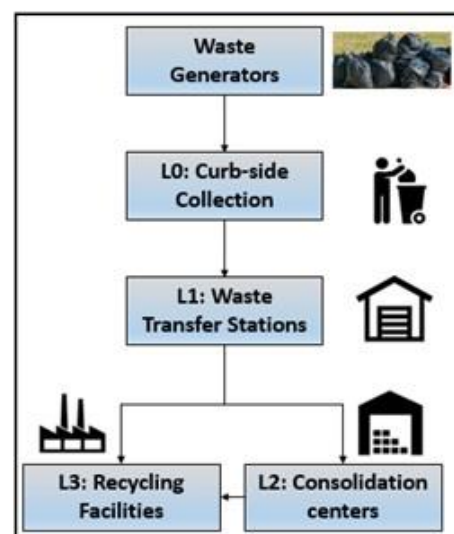


Figure 1. Informal waste sector in Ecuador.

GIS provides an effective tool for characterizing and visualizing geographical distributions of waste and recyclable resources or materials dispersed across urban environments and can be used to capture and analyze location intelligence about the spatial distribution and values of recyclable resources and associated collection systems to effectively empower and inform the policymakers and the broader community with comprehensive, accurate and accessible information.

In this context, the main objective of this paper is to quantify the types and amounts of recyclable materials that waste transfer stations receive and store together with their geo-location in four different cities of the province of Guayas, Ecuador. In addition, this research aims to deliver heat maps for the main collected recyclables through extrapolation done with the software ArcGIS-Pro, allowing to deliver spatial maps stating the quantities of recyclable materials received and collected for the entire study area regardless of the presence of an identified WTS. The rest of this paper is presented as follows. Section 2 shows the materials and methods undertaken to gather the necessary information. Section 3 presents the main results together with the determinants. Finally, section 4 concludes and discusses the subject to offer alternatives and future perspectives.

2. Materials and methods

2.1. The study area

For this research, Guayas province was involved, since it is the most populated out of the 24 provinces of the country, with approximately 4.5 million inhabitants, containing 24.5% of the total population. Greater Guayaquil (Figure 2) is a metropolitan area, formed by the four biggest cities belonging to the province, namely Guayaquil, Samborondon, Daule, and Durán. Together these four cities sum up a total of 3.03 million people, representing 67.33% of the province of Guayas, and 16.94% of the country [10].

2.2. Survey design and data gathering

The questionnaire was submitted between August 15th and September 14th, 2022. The ArcGIS Survey123 application was used, in which an online questionnaire was designed to record data and to geolocate every WTS [12]. The survey consisted of three principal parts. The first part of the questionnaire contained the personal attributes of the owner of the station, such as age, sex, and level of education. The second part had general WTS information, such as the type of property, status of the property, if it was legally registered, number of employees, and storage capacity. The third part contained questions regarding their work as a waste transfer station, such as the type of suppliers they buy from, the types of clients they sell to, types of different metallic, plastic, and paper and cardboard waste, together with the monthly volume they handle. For the collection of information, the research employed a case study approach. Almost 150 students from two local universities participated in the project for the identification, and interview of WTS owners.

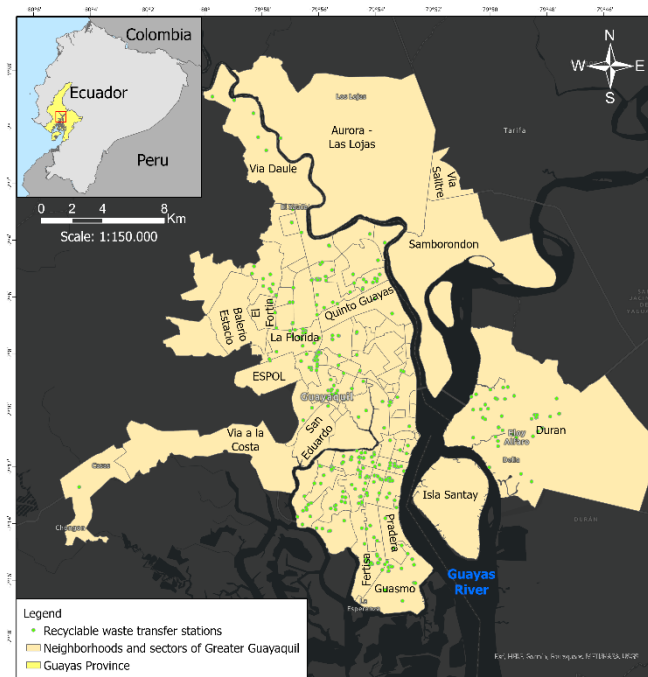


Figure 2. The area of study: Greater Guayaquil

First, the project and its objectives were explained to the students of sustainability courses at both universities. Second, each interested student had two weeks to register a total of five WTSs to confirm their participation. They could choose WTSs from either of the four cities objects of study in Guayas. Third, once confirmed the registered WTSs, willingly participating students were capacitated into the concepts of the survey. Fourth, each student interviewed the owners of their five registered WTSs with the help of their smartphones and the link to the online questionnaire previously set using the survey characteristic of GIS software.

2.3. Data analysis and Heat maps generation on GIS software

For the analysis of the obtained data from the questionnaire and collected waste characteristics, Excel software was used. For the generation of the heat maps, processed data, spatial analysis, and models were integrated within the framework of the GIS project, proving an approach that state and local authorities can use to address environmental protection issues. By processing data in conjunction with spatial statistics, the values from the measured locations could be used to predict values for all locations. Inverse distance weighting (IDW) was used as a preliminary technique for a quick look at interpolated data in the form of two-dimensional horizontal layers of recyclable waste distribution without assessing prediction errors. IDW assumed that each measured point has a local influence that diminishes with distance. It assigned a greater weight to points closer to the prediction location than those farther away; this is what is meant by inverse distance weighting. For the study, heat maps of the six most collected types of residues for each type of waste, namely, copper, scrap metal, newspaper, corrugated cardboard, PET bottles and PVC, were generated.

3. Results

3.1. Description of dataset

Table 1. Characteristics of waste transfer stations (N=562)

| Socio-Demographic Variable | N | Percentage (%) |
|----------------------------|-----|----------------|
| Gender of WTS owner | | |
| Male | 453 | 80.60 |
| Female | 109 | 19.39 |
| Age of WTS owner | | |
| < 26 | 13 | 2.31 |
| 26 – 36 | 105 | 18.68 |
| 37 – 47 | 227 | 40.39 |
| 48 – 58 | 168 | 29.89 |
| 59 – 69 | 37 | 6.58 |
| > 69 | 12 | 2.14 |
| Education of WTS owner | | |
| None | 3 | 0.53 |
| Primary | 44 | 7.83 |
| High School | 277 | 49.29 |
| Technological (2 years) | 66 | 11.74 |
| University (4-5 years) | 162 | 28.83 |
| Post grade | 6 | 1.07 |
| Other | 4 | 0.71 |
| Legally registered company | | |
| Yes | 292 | 51.96 |
| No | 270 | 48.04 |
| Status of WTS | | |
| Own | 392 | 69.75 |
| Rented | 164 | 29.18 |
| Other | 6 | 1.07 |
| Type of property | | |
| Household | 52 | 9.25 |
| Inhabited Dwelling | 22 | 3.90 |
| Cellar | 280 | 49.82 |
| Premise | 192 | 34.16 |
| Other | 16 | 2.85 |
| Number of employees | | |
| None | 10 | 1.78 |
| 1 | 35 | 6.23 |
| 2 – 3 | 181 | 32.21 |
| 4 – 8 | 216 | 38.43 |
| 9 – 15 | 52 | 9.25 |
| > 15 | 68 | 12.10 |
| Storage capacity (tons) | | |
| < 5 | 137 | 24.38 |
| 5 - 10 | 186 | 33.10 |
| 10 - 20 | 111 | 19.75 |
| 20 – 50 | 73 | 12.99 |
| > 50 | 55 | 9.79 |

A total of 562 valid surveys were achieved during the project. The different characteristics of the waste transfer stations, and their owners are shown in Table 1. In general, most of the owners were men (80.60%) and were aged between 26 and 58 years old (88.96%). Most of them were at least high school educated (49.29), however, a surprising amount had university (28.83%) or technical studies (11.74%). Difference between university and technical studies are the number of studying years after high school, normally 2 for technical and at least 4 for university. Regarding the WTSs, they were mostly owned (69.75%), and most of them were located in cellars (49.82%). The number of legally-registered and unregistered WTSs were nearly equal, with registered WTSs only about 2% higher. The number of employees ranged mostly between 2 and 8 workers (70.74%), and their storage capacity was mostly between 5 and 10 tons (33.10%).

3.2. Quantification and characterization of recyclable waste

In table 2, we can see the results for the metal characterization of collected waste. WTSs are mostly interested in buying scrap and copper, followed by steel and aluminum.

Table 2. Types and quantities of monthly kg collected metal recyclable waste.

| Type | None | 0-25 | 26-50 | 51-100 | 101-200 | 201-500 | > 500 |
|------------|------|------|-------|--------|---------|---------|-------|
| Copper | 156 | 79 | 103 | 97 | 45 | 22 | 60 |
| Bronze | 190 | 73 | 111 | 82 | 44 | 22 | 40 |
| Steel | 174 | 72 | 91 | 105 | 48 | 23 | 49 |
| Aluminum | 175 | 63 | 105 | 103 | 45 | 25 | 46 |
| Scrap | 151 | 63 | 82 | 94 | 60 | 43 | 67 |
| Chips | 322 | 57 | 59 | 53 | 33 | 8 | 30 |
| Cans | 207 | 63 | 97 | 75 | 51 | 23 | 46 |
| Appliances | 233 | 67 | 80 | 69 | 44 | 25 | 42 |

In table 3, we can see the results for the paper and cardboard characterization of collected waste. WTSs are mostly interested in buying newspapers and corrugated cardboard, followed by packing boxes and magazines.

Table 3. Types and quantities of monthly kg collected paper and cardboard waste

| Type | None | 0-25 | 26-50 | 51-100 | 101-200 | 201-500 | > 500 |
|---------------------------|------|------|-------|--------|---------|---------|-------|
| Newspaper | 203 | 94 | 75 | 66 | 49 | 25 | 50 |
| Magazines | 212 | 101 | 94 | 60 | 34 | 21 | 40 |
| Kraft Paper | 300 | 77 | 66 | 42 | 21 | 12 | 44 |
| White bond fiber | 299 | 70 | 71 | 38 | 31 | 12 | 41 |
| White fiber printed paper | 313 | 61 | 57 | 44 | 23 | 19 | 45 |
| Corrugated cardboard | 225 | 70 | 80 | 59 | 40 | 32 | 56 |
| Packing | 244 | 72 | 72 | 61 | 35 | 27 | 51 |

| | | | | | | | |
|---------------------|-----|----|----|----|----|----|----|
| boxes | | | | | | | |
| Pasteboard | 292 | 70 | 75 | 44 | 29 | 13 | 39 |
| Cardboard cylinders | 331 | 68 | 49 | 36 | 25 | 10 | 43 |

| | | | | | | | |
|----------------|-----|----|----|----|----|---|----|
| EPS insulation | 393 | 33 | 36 | 31 | 25 | 7 | 37 |
|----------------|-----|----|----|----|----|---|----|

In table 4, we can see the results for the plastic characterization of collected waste. WTSs are mostly interested in buying polyethylene terephthalate (PET) bottles and polyvinyl chloride (PVC), followed by buckets and plastic bags mostly made from high-density polyethylene (HDPE), and low-density polyethylene (LDPE).

Table 4. Types and quantities of monthly kg collected plastic waste.

| Type | None | 0-25 | 26-50 | 51-100 | 101-200 | 201-500 | > 500 |
|-------------------------------|------|------|-------|--------|---------|---------|-------|
| PET bottles | 145 | 68 | 95 | 89 | 57 | 25 | 83 |
| PP Containers | 311 | 59 | 62 | 43 | 36 | 16 | 35 |
| Buckets | 273 | 66 | 79 | 61 | 33 | 18 | 40 |
| Plastic bags | 302 | 60 | 56 | 48 | 33 | 21 | 42 |
| Stretch plastic | 346 | 49 | 44 | 32 | 32 | 15 | 44 |
| Shampoo /Cream/ Other Bottles | 247 | 59 | 85 | 63 | 44 | 17 | 47 |
| EPS containers | 280 | 46 | 64 | 67 | 44 | 19 | 42 |

Figures 3 and 4 show the types of clients and suppliers interviewed at waste transfer stations that they sell to and that they buy from their recyclable waste. For this section, WTSs owners could pick more than one choice, and after it was summed the number of times each choice was chosen and divided by the total number of selections in total. WTSs buy mostly from informal waste pickers (23.73%) and other street waste collectors (19.90%). The difference between them is that for IWPs the collection and selling of recyclable materials is their principal source of income. WTSs most principal clients in order of importance are recycling companies (26.95%), processing companies (26.44%), and industries (25.33%).

3.3. GIS Heat Maps

Figure 5 shows the colored heat maps for Greater Guayaquil. The two most collected types of waste for each category were used. Heat maps represent the average values of each waste generation of copper, scrap metal, newspaper, corrugated cardboard, PET bottles, and PVC. For the calculations, the represented points were located in the neighborhood-divided map and collected to calculate the average. Following, the heat maps were interpolated using the inverse distance weighting method to obtain different shades of colors going from pale yellow (least average generation) to brown (highest average generation).

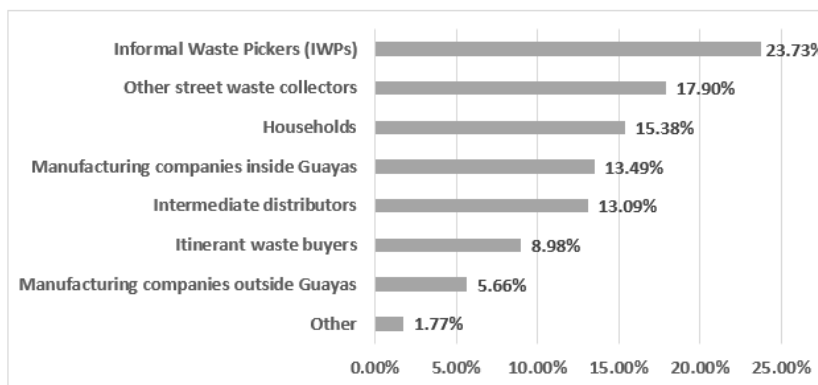


Figure 3. Places where WTSs purchase their waste.

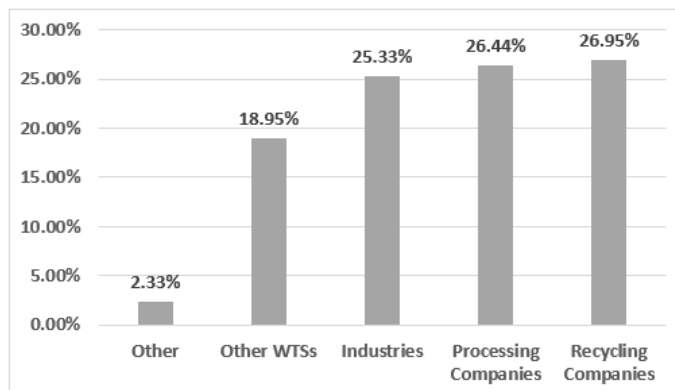


Figure 4. Types of clients to whom WTSs sell their waste.

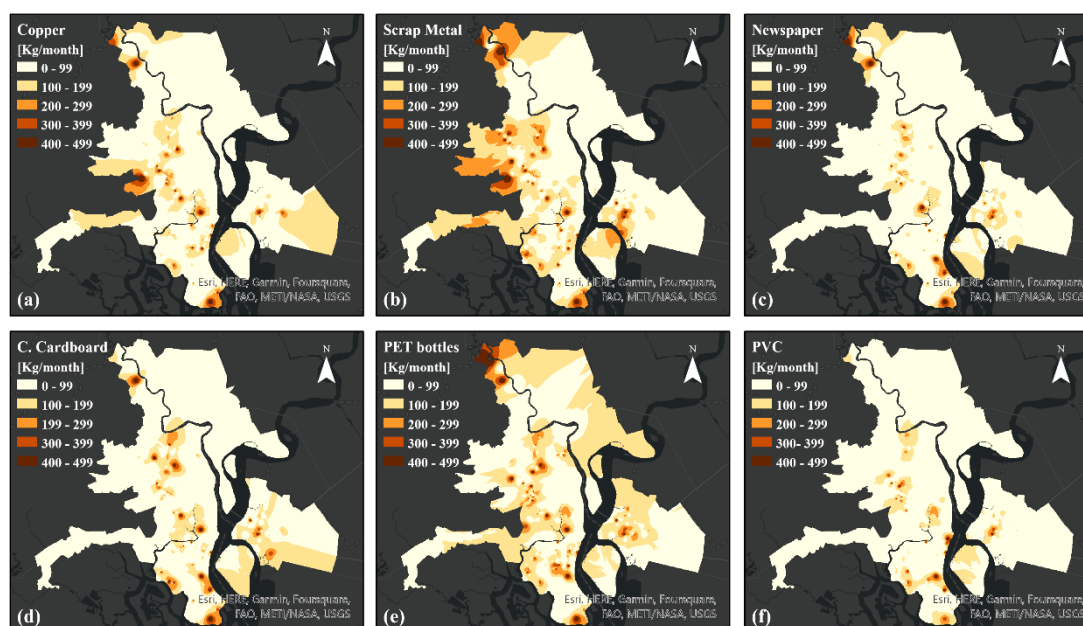


Figure 5. Heat maps for the most recycled waste in Greater Guayaquil, copper (a), scrap metal (b), newspaper (c), corrugated cardboard (d), PET bottles (e), and PVC (f).

4. Discussion and conclusion

This research aimed to determine the geo-location of the waste transfer stations in Gran Guayaquil, formalize the quantities of the different collected recyclable materials, and extrapolate the quantities for all the Grand Guayaquil area with the help of geographical information software. The most recycled types of waste were copper, scrap metal, newspaper, corrugated cardboard, PET bottles, and PVC. To the best of our knowledge, this is the first study that has covered such a big sample of waste transfer stations for a South American city. Insufficient collection, uncontrolled street collection points, and improper disposal in open dumps allow the refuse to be readily available for the informal sector. Informal recycling provides employment and a livelihood for impoverished, marginalized, and vulnerable individuals or social groups [12]. Despite their particularly adverse working conditions, it is important to recognize that these activities allow those involved to survive and be employed in regions that have high unemployment rates.

Future research should try to include these results to develop an inverse logistic system to improve the current collection rates through the formalization of these waste transfer stations. Additionally, municipalities can utilize the informal infrastructure to bring down operational costs; waste management firms can source from it; corporations can carry out their extended producer responsibility through it; apartments and small businesses can send their recyclable waste directly to informal stakeholders, such as waste transfer stations, that are part of the informal sector ecosystem.

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