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Informal waste pickers in guayaquil: Recycling rates, environmental benefits, main barriers, and troubles

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ABSTRACT

Systems for managing municipal solid waste are typically ineffective in developing nations because of governments' deficient financial and administrative frameworks, poor rules, and a lack of suitable infrastructure and human resources. The informal sector plays an essential role in these systems by reprocessing waste into secondary raw materials, reducing collection and disposal costs, and, most importantly, benefiting the environment by avoiding incineration and landfilling. However, their actual contributions remain unknown. The present paper aims to understand the role of informal waste pickers (IWPs) in the waste management system of Guayaquil City and their environmental impact through the calculations of the carbon footprint (CF) avoided due to their aid. The survey design gathered information on their personal profiles, types, and rates of collected recyclables, market conditions, their main barriers, and troubles regarding their formalization. The results of the survey demonstrate that waste picking is mostly a male-driven activity, the average daily mass collected per IWP is 13 kg, the most collected recyclable waste is polyethylene terephthalate, their average monthly income is $179, and the total avoided CF of the entire informal waste picking process is almost 14 thousand tons of CO_2 eq yearly. Further, IWPs prefer to operate alone, and only 16% of them would join a cooperative, despite their numerous financial, logistical, and personal challenges.

1. Introduction

Over the past few decades, world economies and populations have increased the consumption of commodities and items intended to be thrown away [1]. According to projections, the globe will produce 2.2 billion tons of garbage by 2025, with a management cost of almost 375.50 billion dollars annually [2]. Since the commencement of large-scale industrial manufacturing in 1950, humanity has generated more than eight billion metric tons of plastic waste as of 2015 [3]. Pollution of the air, water, and land results from inadequate garbage collection and treatment [4]. Uncontrolled waste also contributes to the accumulation and spread of other

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illnesses, including cholera and malaria, which have already claimed millions of lives [5–7].

Systems for municipal solid waste management (MSWM) are typically ineffective in developing nations like Ecuador because of the local governments' deficient financial and administrative frameworks, poor rules, and a lack of suitable infrastructure and human resources [8,9]. A total of 0.61 kg of domestic waste is generated daily in the city of Guayaquil, from which almost 75% is organic, 8% plastic, 6% paper, and cardboard, 6% for glass and dust, and 4% for metal and others [10]. Fig. 1 shows more information on the country's waste generation by 2017.

The informal sector is primarily responsible for garbage management and recycling in low- and middle-income nations in the developing south hemisphere (Africa, Asia, Latin America, and the Caribbean) [11,12]. The informal sector is characterized by small-scale, labor-intensive, unregulated, and unregistered provision of services. It entails gathering recyclables from dumps, streets, or directly at the point of production (homes, businesses), then passing them along to intermediaries before arriving at recycling facilities [13,14]. Individual employees and businesses in the informal sector do not pay taxes but do not have access to government insurance or social welfare programs.

The informal sector plays a vital role in any MSWM system by reprocessing waste into secondary raw materials, reducing collection and disposal costs, and, most importantly, benefiting the environment by avoiding incineration and landfilling [16].

The informal sector comprises individuals or enterprises involved in recycling and waste management activities not sponsored, financed, recognized, or allowed by the formal solid waste authorities [17]. According to recent research, informal recycling programs typically attain recycling rates of 20–30% [12]. In some situations, they are the only organized recycling programs available in many developing nations [18]. For the local manufacturing sector, informal recycling can offer a consistent, reliable supply of secondary raw materials to replace more expensive imported raw materials.

The foundation of the informal sector pyramid's workforce is made up of informal waste pickers (IWPs) [11]. They are experts at spotting trash that could be valuable. Typically, they gather abandoned waste materials and add value by collecting them in commercially acceptable amounts or sorting, cleaning, or compacting them to make transit easier [19]. They carry out the earliest phases of extracting recyclables from mixed garbage, which are the most labor-intensive and least gratifying.

Poor and marginalized socioeconomic groups rely on scavenging and rubbish picking as a source of income and, in some circumstances, even daily survival, engage in informal waste collection. Sorting and recycling waste products is a vital part of the livelihoods of up to 20 million people worldwide, or 0.5% of the metropolitan population [12]. It is a demanding and dangerous job that exposes these workers to dangers like infections, sharp items, toxic chemicals, and rabid animals [20]. One previous study revealed that this profession's most cited occupational hazards are physical, social, biological, chemical and safety, ergonomic, and

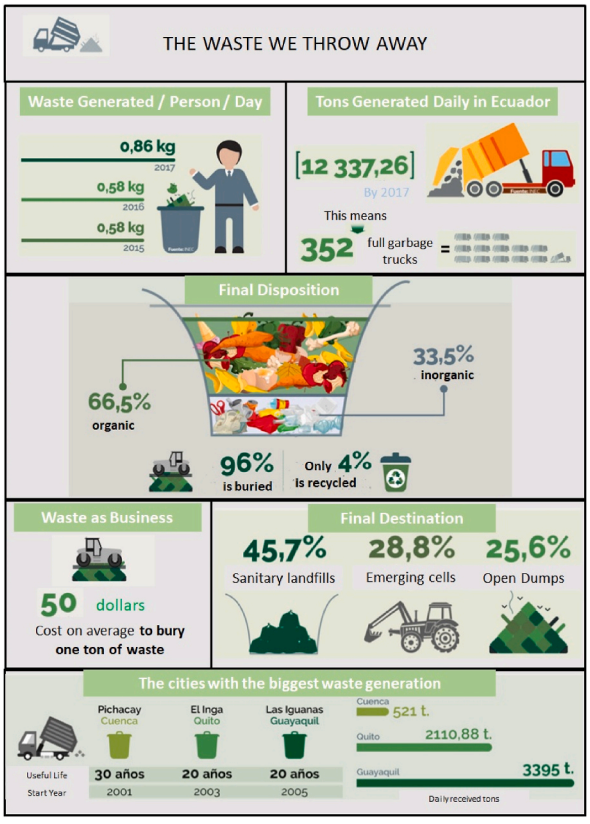

Fig. 1. Waste management in Ecuador (adapted from Ref. [15]).

mechanical, and the most health issues include epidermal, musculoskeletal, and respiratory diseases [21].

Typically, household and commercial waste is not source-separated in Guayaquil, which means recyclable materials are mixed with organic waste and other contaminants. Usually, this material is dumped at a designated dumpsite or curbside in front of the residence or business for pick-up. The IWPs then transport their collected yield to an aggregator L1, a collection center, a rubbish store, or a waste transfer station. These L1 aggregators usually communicate with L0 directly. However, some make direct purchases from companies or work as pickers themselves. In the waste value chain, these stations provide the first point of tradeable consolidation. Transfer stations can differ widely in size, infrastructure, and arrangement throughout Ecuador, especially in Guayaquil. L1 aggregators are typically family-owned firms that trade with IWPs and have the basic infrastructure. They allow temporary storage before transportation to other bigger L2 consolidation centers or L3 recycling facilities. Fig. 2 shows how waste is managed in Guayaquil, including recyclers within the system.

IWPs contribute to the city's waste collection system uniquely. They influence the environment by lowering greenhouse gas (GHG) emissions due to reducing the amount of garbage discarded at dumpsites and transportation expenses [22,23]. The Carbon Footprint (CF) is a tool for calculating GHG emissions avoided due to the avoidance of waste streams plus transportation to their final disposal sites. Due to economic considerations, plastic, glass, metal, and paper are the materials that informal waste pickers tend to collect the most. The numbers in Table 1 correspond to Ecuador's three largest cities.

The present research has a quadruple objective. The first goal is to undertake a socioeconomic analysis of the Guayaquil urban waste sector's informal waste pickers. Estimating the amount of recyclable waste that has been collected is the second goal. The third goal is to determine how much GHG emissions have been reduced due to transportation alternatives and landfill avoidance by calculating the CF averted. Furthermore, finally, the fourth objective is to analyze IWPs' opinions on the main advantages and disadvantages of their profession, together with their input on the formalization process. One previous effort examined informal workers' activities in Cuenca [24]. However, their study was based on a survey by the NGO Alliance for the Development of the Inclusive Recycling Plan [25], an external organism, and their sample was lower than the one used in this study.

2. Materials and methods

2.1. Study Area

The provincial capital of Guayas, Guayaquil, is situated in Ecuador's coastal region on the Pacific Ocean coast (Fig. 3). Despite only making up 2.23% of the province, with a total area of 344.5 km^2, it is the second most populated city in the nation after Quito, accounting for 61.81% of the province's population and 14.99% of the national population. In 2018, the city contributed over 20% of the nation's Gross Domestic Product. The primary economic activity in Guayas comprises 43% commerce, 25% services, 19% industry and manufacturing, 11% the primary sector, and 2% construction.

2.2. Survey design and data collection

In order to answer objectives one, two, and four, a survey was designed to gather the necessary information on the IWP's personal profiles, the types and rates of collected recyclable waste, the market conditions for their obtained materials, the main barriers they face during their work, and the troubles they encounter regarding their possible formalization.

The survey consisted of four segments, as shown in Table 2. The first part of the survey contained (Questions 1 to 5) the personal attributes of the interviewed person, such as gender, age, education level, household size, and level of income. The second part (Questions 6 to 10) had general information regarding their collection activities, such as type of worker and collection, daily working kilometers and hours, and type of waste collected. The third segment asked for information regarding the collected mass and trading information (Questions 11 to 17). The fourth and last segment collected information regarding the IWPs' opinions on the main troubles and benefits of working in the informal sector and their opinion regarding formalization (Questions 18 to 25).

The survey was evaluated and amended following a pilot pre-test to remove errors, misinterpretations, or typos. Individual interviews conducted by engineering students from two nearby local universities in the city served as the survey strategy. In December

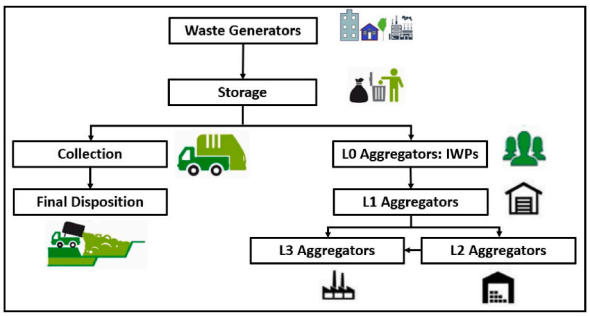

Fig. 2. Urban waste management in Guayaquil.

Table 1
Main recyclable waste collected by IWPs in Ecuador.

Material	Guayaquil	Quito	Cuenca
White Paper	12%	10%	15%
Newspaper	14%	7%	12%
Cardboard	16%	17%	15%
Soft Plastic (LDPE)	13%	10%	13%
Hard Plastic (HDPE)	9%	8%	11%
Polyethylene Terephthalate PET	20%	24%	13%
Glass	11%	3%	6%
Metals	5%	19%	12%
Electronic Waste	0%	2%	3%

Source: IRR, 2015

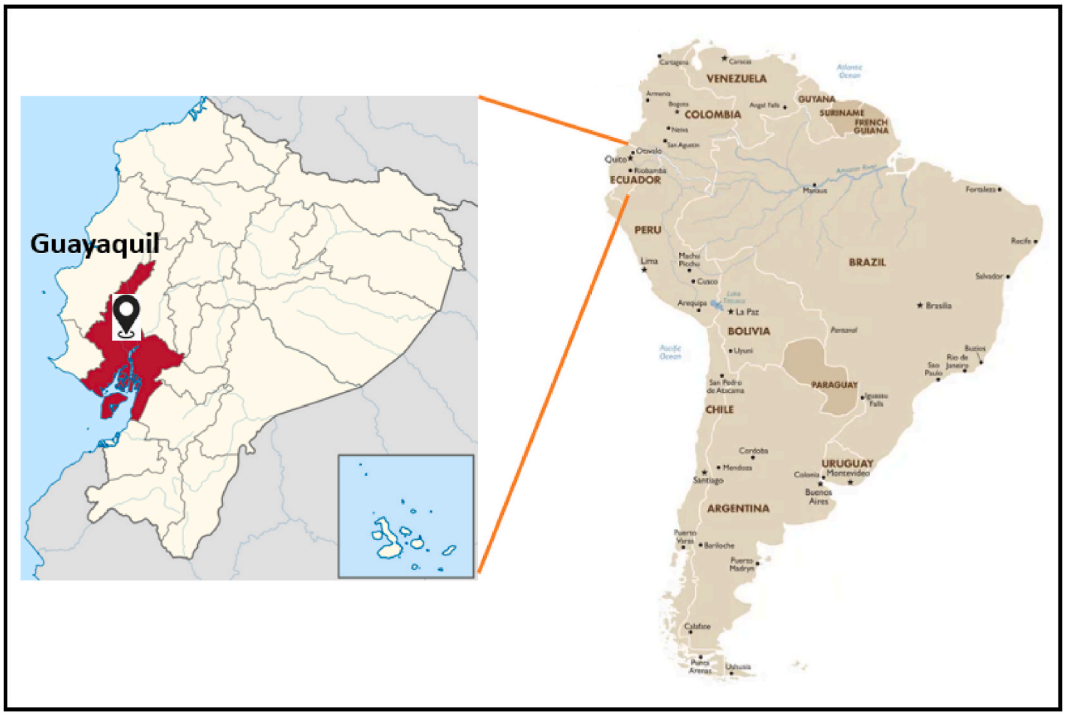

Fig. 3. Study area.

2021, the students received prior instruction on the survey's topics. In order to increase the survey area, participating students had to get in touch with two IWPs in the city close to their households or from their neighborhoods. Every IWP who agreed to participate in the study was first introduced to the research objective. Participants were also informed that their personal information would not be revealed, and every interviewed IWP signed informed consent forms before the start. Before allowing students to enter the data on an Excel spreadsheet for further statistical usage, the author double-checked the completed questionnaires to ensure all parts were filled out.

The survey was conducted among several informal waste pickers in Guayaquil between January and March 2022 using a non-probabilistic sampling. Equation (1) was used to determine the sample size, and a 95% confidence level was used.

$$n = \frac{k^2 * p * q * N}{e^2(N-1) + K^2 * p * q} \tag{1}$$

N is the total population of informal waste pickers (4000 IWPs according to the municipality of the city [26], k is the confidence level (95.0%), p = 0.4, q = 0.6, and e is the sampling error, which in this instance was 6.2% for a total of 227 validated surveys at the end.

2.3. Estimation of daily collected recyclable waste by IWPs

According to the Municipality of Guayaquil data, the city has approximately 4000 IWPs [26]. The following equation (2) was

Table 2
The submitted household questionnaire (English translation and adaptation).

No.	Question	Answers allowed
1	Gender	Male; Female.
2	Age	<26; 26–36; 37–47; 48–58; 59–69; >69.
3	Education Level	None; Primary School; High School; University; Post-Grade.
4	Household Size	1; 2; 3; 4; 5–6; >6.
5	Level of income	Less than $150.00; $151.00 - $300.00; $301.00 - $450.00; $451.00 - $600.00; $601.00 - $750.00.
6	Type of worker	Household collector; Street recycler; Itinerant waste buyer; Dumpster collector; Intermediary; Trader (Buy/Sell).
7	Type of collection	Walking; Hand-carriage; Bicycle; Small vehicle; Trolley car, Other.
8	Kilometers worked daily	Less than 5; 5–10; 11–15; 16–20; More than 20.
9	Daily working hours	Less than 2; 2–6; 7–10; 11–16; More than 16.
10	Type of recyclable waste collected by IWPs (more than one option could be declared)	White paper; Newspaper; Cardboard; Soft Plastics (LDPE); Hard Plastics (HDPE); PET plastics; Aluminum; Glass; Tin cans and jars; Electronic waste.
11	Quantities of collected waste daily: White paper; Newspaper; Cardboard; Soft plastic; Hard plastic; PET bottles; Iron; Glass; Aluminum; Electronic waste.	None; 0.0–0.5; 0.5–2.0; 2.0–4.0; >4.0
12	Places IWPs sell their products to	Intermediate Concessionaries; Plastic, Metal, and Glass Manufacturing Companies; Plastic Recycling Companies; Others.
13	Selling cost of collected waste per kilogram: White paper; Newspaper; Cardboard; Soft plastic; Hard plastic; PET bottles; Iron; Glass; Aluminum; Electronic waste.	Mean; Standard Deviation
14	Forms IWPs sell their products.	Pellets; Grinded; As they collect them; Flakes; Others.
15	Ways IWPs classify their collected plastic waste.	Type of polymer; Purity; Colour; Other.
16	What factors increase the cost of collected trash? (More than one choice may be stated.)	Buyers' standards; Price of virgin resin; Quality of collected materials; Reprocess technology installed; Offer/Demand Market
17	How can you add value to the waste you collect? (More than one choice may be stated.)	Cleaning them; Classifying them into categories; Washing and Drying them; Compacting them; Grouping them; Other.
18	Reasons why you consider an IWP job better than other sorts of jobs? (more than one option could be declared).	As an IWP I gain more money; There is more freedom; I have money in my pocket every day; As an IWP I suffer less; In the informal collection there are always jobs; The IWP profession gets help from others; Another Reason; None of the above.
19	What would you ask the Municipality to help with?	Capital; Transport; Personal Protective Equipment (PPE); Making households sort their waste at home; Nothing.
20	From your perspective, what is the main problem with informal recycling?	Lack of transport; Price fluctuations; Negative public perception; Lack of capital; Lack of PPE; Lack of cleaning facilities.
21	From your perspective, what is the main challenge with the transport of recyclable waste?	Walking long distances; Costly; Dangerous materials; Voluminous materials, Other.
22	Would you like to join a cooperative of IWPs?	I already belong to one; I'd like to join immediately; I'd like to continue on my own; I'll wait to see the evolution.
23	What is the main reason you would participate or not in an IWP's cooperative?	Increase my income; Used to work alone; Prevent conflict; It reduces my gains; free transport.
24	How much do you agree with the following statements to you in terms of their incorporation into the formal waste collection system? 24.1 Domestic garbage is separated from other materials. 24.2 Door-to-door recycling pick-up by lone recyclers. 24.3 Giving recyclers contracts for waste collection. 24.4 Make recycling companies' gathering of plastic garbage legal. 24.5 Teaching recyclers about the many types of waste and how to gather them. 24.6 Establish markets where recyclers can sell the waste they have gathered. 24.7 Offering financing to recyclers so they can buy storage or delivery facilities. 24.8 Teach recyclers on how to protect the environment and their health. 24.9 Giving recyclers official clothes and identification cards so they may be recognized in public. 24.10 An increase in facilities for recycling and rubbish collection. 24.11 Establish recycling goals for plastic garbage to motivate recyclers to gather more trash. 24.12 Increase public awareness of the value of recyclers in the supply chain.	Totally Disagree; Partially Disagree; Neutral; Partially Agree; Totally Agree.
25	How important is each of the following challenges to you? 25.1 A lack of waste classification tools. 25.2 The lack of community trash separation. 25.3 A lack of municipal and community support. 25.4 A lack of knowledge about waste collection and classification. 25.5 A lack of trash transportation tools. 25.6 The absence of markets for our recycled plastic.	Totally Unimportant; Partially Unimportant; Neutral; Partially Important; Totally Important.

(*continued on next page*)

Table 2 (*continued*)

No.	Question	Answers allowed
	25.7 A lack of government support for recycling and rubbish collection in the informal sector. 25.8 The absence of laws and regulations governing the recycling of plastic garbage. 25.9 The lack of official legal recognition of recyclers in waste management systems. 25.10 The absence of systems for collecting plastic garbage for recovery. 25.11 A lack of understanding of the role played by the unorganized sector in the waste recovery process.	

modified and used based on the calculations previously done by Ref. [27] to estimate the mass collection of recyclable waste's different types. This equation allows estimating the minimum collected values considering the percentages obtained during the taking of the survey. As shown in the survey design, each IWP was given ranges of kilograms collected of every type of recyclable waste (none, between 0.0 and 0.5, between 0.5 and 2.0, between 2.0 and 4.0, more than 4.0). The percentages of the number of IWP choosing each range were taken and used in equation (2) to get an average on the total quantities.

$$TW = \frac{\sum T_P * (0 * \%None + 0{,}25 * \%(between\ 0{,}0\ and\ 0{,}5) + 1{,}25 * \%(between\ 0{,}5\ and\ 2{,}0) + 3{,}00 * \%(between\ 2{,}0\ and\ 4{,}0) + 4 * \%(more\ than\ 4{,}0)}{100\%} \quad (2)$$

TW is the total quantity of each expected collected recyclable waste daily per IWP, and Tp is the total IWPs population. We considered the average value of every range of mass as the collected value and multiplied it by the percentage of times this value was selected. Finally, we summed it all up to obtain the total waste collected daily in Kg per day.

2.4. Assessment of avoided GHG emissions

Along with minor CO_2 emissions from landfills and the incineration of solid waste containing fossil carbon, plastics, and synthetic textiles, the waste sector contributes to about 5% of GHG emissions and 20% of global CH4 emissions [28]. In the case of Guayaquil, the Las Iguanas landfill received approximately 29 million tons of waste from 1994 to 2020, of which approximately 66.5% was organic [29]. Also, landfilling emits almost 400 kg CO2 eq per tonne of organic waste, making it the option with the highest GHG intensity [30].

Creating a sustainability analysis utilizing sustainability indicators like Carbon Footprint (CF) is vital to fully comprehend the environmental advantages of the IWPs collection procedure and the role of IWPs in the environment. Businesses can use this indicator as a sustainability indicator because it is inextricably linked to the life cycle thinking idea. An earlier study used this sustainability indicator to demonstrate the environmental advantages of various expanded polystyrene recycling scenarios, finding out that this indicator enables a more thorough evaluation of the environmental advantages of any recycling program for all stakeholders working at different levels of the waste management hierarchy, from managers to politicians [31].

The contemporary governmental and corporate goals now include CF, which impacts the global exchange of commodities and services [32]. It evaluates the overall balance of greenhouse gas (GHG) emissions and sinks from a system, service, or product throughout its life cycle [33]. Within a predetermined system boundary, it considers all inputs and processes.

As illustrated in Fig. 4, collecting recyclable waste by IWPs lessens the quantity of waste in landfills while minimizing the effects of transportation from the curbside to the landfill. According to the baseline scenario, all recyclable waste that would otherwise be collected by IWPs is taken to the nearby landfill and dumped there without being classified. There is also a comparative case where the

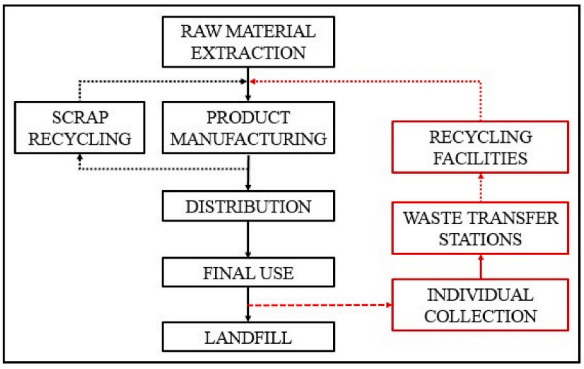

Fig. 4. Linear and circular economy [31].

collected material is sold to waste transfer facilities for additional processing (Hidalgo et al., 2020).

The difference between the emissions from transporting and burying all recyclable items (the baseline scenario) and the emissions from gathering them for further use is what is used to calculate the GHG emissions averted by the recyclers of Guayaquil, Ecuador (comparison scenario). CF is determined using equation (3):

$$Avoided\ CF = CF_{Baseline\ Scenario} - CF_{Comparison\ Scenario} \quad (3)$$

The assessment of avoided CF is carried out according to the following considerations.

a) It is considered trucks of 19 m^3 and 14 tons' capacity for transportation. As a reference, a garbage truck travels between 20 and 37 km in one work journey. An average of 28.5 km is considered for this study.
b) For landfill, it is considered that all waste is buried at the "Las Iguanas" complex without previous classification.
c) For the case of comparison scenario, it is considered that the collection activity produces no environmental impacts because most of the collection is done by human power.

Values on CF were obtained with the help of SimaPro 9.1 software, Ecoinvent 3.0, and Industry 2.0 databases. The inventory chosen from both databases is shown in Table 3.

3. Results

3.1. Demographic profile of IWPs

Table 4 shows the demographic profile of the total sample population, with 83% being males. Also, the differences between genders are shown for the different characteristics. Most male IWPs are between 26 and 36 years old (26.60%), and the female IWPs are between 48 and 58 years old. For the case of the education level, almost 95% have completed at least primary school having similar profiles for both genders. In a nation where the minimum salary is $420.00, roughly 77% of the population earns less than $300 per month, making the income level for this job meager. However, this value is far more than that of Nicaraguan waste pickers, who receive between $45.00 and $60.00 per month, and comparable to IWP salaries in more industrialized nations like Mexico, India, and Brazil, which exceed $210.00 per month [20]. There are evident gender disparities in the feature of home size. While most males (almost 30%) live alone, most females (52%) are in households with three to four people.

3.2. Working conditions of IWPs

66% of IWPs reported being street recyclers that go through the garbage bags left by the population from households and commercial businesses at the curbside before the time of arrival of the garbage trucks. Most male and female IWPs identify as street recyclers, followed by household collectors, who go house by house, taking the recyclable waste (See Table 5). As shown in Photo 1, Fig. 10 a more considerable portion of IWPs prefers walking to collect their waste (40%) with the help of plastic bags, while using devices to carry waste, such as hand-carriage or trolley cars, represent an additional 40%. Females prefer trolley cars while walking, rather than males who prefer walking and carrying their collected waste by hand. Half the sampled population covers less than 10 km daily, and approximately 65% work between 2 and 10 h daily. Finally, households, dumpsters, and markets are the preferred places to gather recyclable waste, with 36%, 35%, and 20%, respectively.

Fig. 5a shows the main challenges IWPs face in order of importance: price fluctuations, unfavorable public perceptions, transportation, a lack of personal protective equipment (PPE), and inadequate cleaning facilities. These findings are consistent with other authors [12,34,35]. It is clear that pricing changes are the most significant factor for recyclers, and these are related to societal challenges and exposure to occupational risks. The fact that recyclers are perceived negatively by the general public may be because they are perceived as poor and, therefore, not contributing to Ecuadorian society. In some cases, their presence can be confused with delinquents. Instead, Fig. 5b highlights the significant difficulties associated with moving recyclable waste, with walking vast distances

Table 3
Inventory used for the CF avoidance quantification.

No.	Item	Database
1	Municipal solid waste (waste scenario) {CH} | Treatment of municipal solid waste, landfill | Conseq, S.	Ecoinvent 3.0
2	Iron scrap, unsorted {GLO} | market for | APOS, U.	
3	Packaging glass, white {GLO] | packaging glass production, white without cullet | Conseq, S.	
4	Paper, melamine impregnated {GLO} market for | Conseq, S.	
5	Waste newspaper {GLO} waste newspaper, Recycled content cut-off, U.	
6	Corrugated board box {GLO} | market for corrugated board box | APOS, U.	
7	Aluminum scrap, post-consumer {GLO} aluminium scrap, post-consumer, Recycled content cut-off, S.	
8	LDPE bottles, E.	Industry data 2.0
9	HDPE bottles, E.	
10	PET, bottle grade, at plant/RER.	
11	Lorry transport, EURO, 0, 1, 2, 3, 4 mix, 22 t total weight, 17,3 t max payload RER S.	

Table 4
Demographic characteristics of the sampled population (N = 227).

Demographic Value	N	Male	Female
Gender			
Male	188 (82.82%)	–	–
Female	39 (17.18%)	–	–
Age			
<26	58 (25.55%)	53 (28.19%)	5 (12.82%)
26–36	58 (25.55%)	50 (26.60%)	8 (20.51%)
37–47	51 (22.47%)	44 (23.40%)	7 (17.95%)
48–58	38 (16.74%)	28 (14.89%)	10 (23.64%)
59–69	16 (7.05%)	12 (6.38%)	4 (10.26%)
>69	6 (2.64%)	1 (0.53%)	5 (12.82%)
Education Level			
None	5 (2.20%)	4 (2.13%)	1 (2.56%)
Primary School	105 (46.26%)	85 (45.21%)	20 (51.28%)
High School	109 (48.02%)	93 (49.47%)	16 (41.03%)
University	7 (3.08%)	5 (2.66%)	2 (5.13%)
Post-Grade	1 (0.44%)	1 (0.53%)	0 (0.00%)
Level of income			
Less than $150.00	139 (61.23%)	114 (60.64%)	25 (64.10%)
$151.00 - $300.00	57 (25.11%)	50 (26.60%)	7 (17.95%)
$301.00 - $450.00	17 (7.49%)	15 (7.98%)	2 (5.13%)
$451.00 - $600.00	5 (2.20%)	3 (1.60%)	2 (5.13%)
$601.00 - $750.00	7 (3.08%)	4(2.13%)	3 (7.69%)
More than $750.00	2 (0.88%)	2 (1.06%)	0 (0.00%)
Household Size			
1	64 (28.19%)	56 (29.79%)	8 (20.51%)
2	36 (15.86%)	35 (18.62%)	1 (2.56%)
3	56 (24.67%)	46 (24.47%)	10 (25.64%)
4	35 (15.42%)	25 (13.30%)	10 (25.64%)
5–6	19 (8.37%)	16 (8.51%)	3 (7.69%)
>6	17 (7.49%)	10 (5.32%)	7 (17.95%)

Table 5
Demographic characteristics of the sampled population (N = 227).

Demographic Value	N	Male	Female
Type of worker			
Household collector	49 (21.59%)	34 (18.09%)	15 (38.46%)
Street recycler	149 (65.64%)	132 (70.21%)	17 (43.59%)
Itinerant waste buyer	4 (1.76%)	2 (1.06%)	2 (5.13%)
Dumpster collector	11 (4.85%)	11 (5.85%)	0 (0.00%)
Intermediary	11 (4.85%)	8 (4.26%)	3 (7.69%)
Trader (Buy/Sell)	3 (1.32%)	1 (0.56%)	2 (5.13%)
Type of collection			
Walking	91 (40.09%)	80 (42.55%)	11 (28.21%)
Hand-carriage	41 (18.06%)	31 (16.49%)	10 (25.64&)
Bicycle	12 (5.29%)	11 (5.85%)	1 (2.56%)
Small vehicle	10 (4.41%)	8 (4.26%)	2 (5.13%)
Trolley car	57 (25.11%)	47 (25.00%)	13 (33.33%)
Other	16 (7.05%)	11 (5.85%)	2 (5.13%)
Kilometers worked daily			
Less than 5	57 (25.11%)	41 (21.81%)	16 (41.03%)
5–10	74 (32.60%)	62 (32.98%)	12 (30.77%)
11–25	48 (21.15%)	43 (22.87%)	5 (12.82%)
16–20	25 (12.33%)	23 (12.23%)	2 (5.13%)
More than 20	23 (10.13%)	19 (8.37%)	4 (10.26%)
Daily working hours			
Less than 2	28 (12.33%)	15 (7.98%)	13 (33.33%)
2–6	81 (35.68%)	67 (35.64%)	14 (35.90%)
7–10	66 (29.07%)	59 (31.38%)	7 (17.95%)
11–16	37 (16.30%)	34 (18.09%)	3 (7.69%)
More than 16	15 (6.61%)	13 (6.91%)	2 (5.13%)
Where do you get your waste from?			
Households	81 (35.68%)	56 (29.79%)	25 (64.10%)
Schools	12 (5.29%)	12 (6.38%)	0 (0.00%)
Stores/Markets	46 (20.26%)	42 (22.345)	4 (10.26%)
Dumpsters	79 (34.80%)	74 (39.36%)	5 (12.82%)
Others	9 (3.96%)	4 (2.13%)	5 (12.82%)

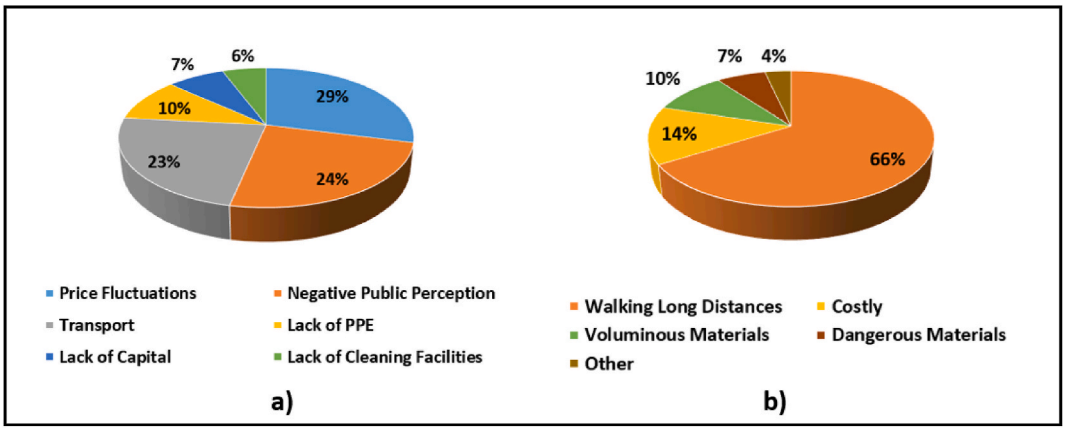

Fig. 5. Main problems in the recycling process: a) Difficulties experienced by IWPs, b) Challenges of transporting waste.

being the most prominent. Another transportation issue is the lack of selective garbage collection routes in the city, which makes recyclers' work more difficult. Additionally, there is no habit of sorting trash at home and no government-sponsored recycling initiatives for households. Recycling workers are exposed to occupational risks due to this mentality because they frequently reach into trash bags and bins without gloves.

Fig. 6 demonstrates why IWPs prefer this kind of informal job over others—the first majority (37%) like work availability and having money in their pocket daily. The second majority enjoys working alone, not having to answer to anyone, and having a schedule that fits their availability.

3.3. Recyclable waste: mass collection and market conditions

Fig. 8a shows that paper and cardboard waste (white paper, newspaper, corrugated cardboard) are the most collected items by IWPs with almost 36%, followed by plastics (HDPE, LDPE, and PET) with approximately 33%. Preferred metal waste collected is tin cans and jars, with 12%, and only 5% reported collecting electronic equipment. Of those who collect plastic waste, 66% recover plastic bottles, bags, and containers, representing 17%. Fig. 8b illustrates the preferred form in which IWPs collect plastic waste, bottles the most collected, as expected from previous experiences [35]. Bags are the second most collected plastics, typically composed of HDPE or LDPE.

Table 6 shows the results for the different recyclable waste collected by IWPs in Guayaquil, together with ranges of mass values. Also, its last column shows the total calculated expected amount of collected recyclable waste per day per IWP following equation (2) from the last section. It is notorious that IWPs are primarily interested in white paper (2.57 kg/day/IWP) and cardboard (2.08 kg/day/IWP). Plastic waste (Soft, Hard, and PET) sums up to 3.96 kg/day/IWP being soft plastic (LDPE), the most collected. Regarding metal waste, aluminum is at the top (1.25 kg/day/IWP), followed by iron (1.16 kg/day/IWP). Electronic waste remains the lower type of generally collected, with only 0.70 kg/day/IWP.

IRR asserts that recyclers sell their collected materials to small and medium-sized companies, or "brokers," who can transport, process, store, and trade with nearby industries. Depending on the materials' quantity, quality, and industrial sector, the broker

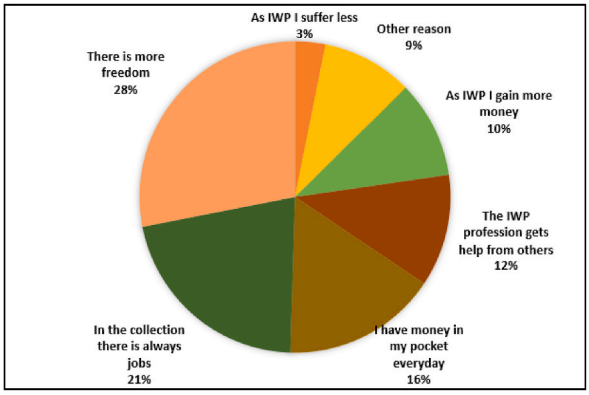

Fig. 6. Reasons why the IWP job is better than others (more than one option could be declared). Most of the IWPs would like help with capital (30%), followed by transport (29%), and in third place, they need personal protective equipment (PPE) with 26% (See Fig. 7).

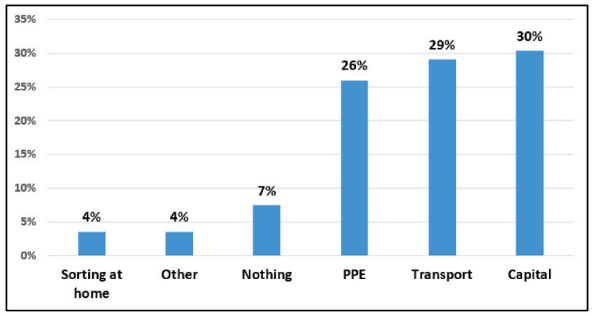

Fig. 7. Wishes IWPs would like help with by the municipality.

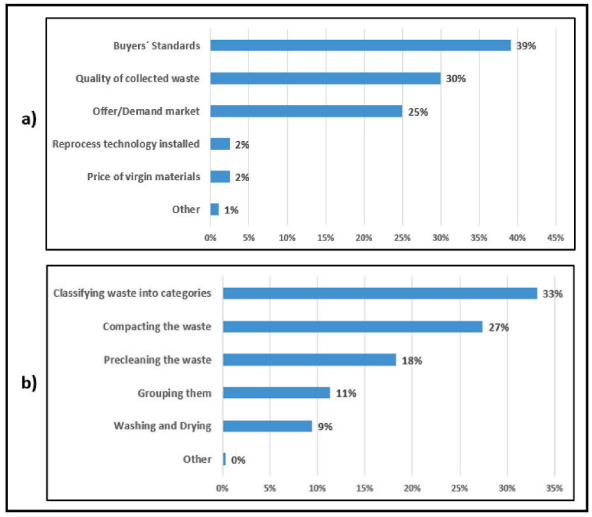

Fig. 8. Recyclable waste collected by the IWPs: a) Types of materials, b) Forms of plastic waste collected.

Table 6
Types and quantities of daily collected recyclable materials by IWPs (N = 227).

Type	None	0.0–0.5	0.5–2.0	2.0–4.0	>4.0	Daily Collection (kg/day/IWP)
White Paper	6(2.64%)	9(3.96%)	68(30.00%)	80(35.24%)	64 (28.19%)	2.57
Newspaper	115(50.66%)	48(21.15%)	29(12.78%)	23(10.13%)	12(5.29%)	0.73
Cardboard	31(13.66%)	23(10.13%)	61(26.87%)	61(26.87%)	51(22.47%)	2.08
Soft Plastic	72(31.72%)	24(10.57%)	54(23.79%)	40(17.62%)	37(16.30%)	1.50
Hard Plastic	83(36.56%)	28(12.33%)	43(18.94%)	41(18.06%)	32(14.10%)	1.37
PET Bottles	111(48.90%)	28(12.33%)	32(14.10%)	23(10.13%)	33(14.54%)	1.09
Iron	115(50.66%)	24(10.57%)	27(11.89%)	21(9.25%)	40(17.62%)	1.16
Glass	125(55.07%)	34(14.98%)	35(15.42%)	20(8.81%)	13(5.73%)	0.72
Aluminum	88(38.77%)	37(16.30%)	39(17.19%)	27(11.89%)	36(15.86%)	1.25
Electronic Waste	131(57.71%)	37(16.30%)	27(11.89%)	13(5.73%)	19(8.37%)	0.70
Total Waste Collected Daily						13.17

decides the purchase price for recyclers (Burneo et al., 2020). Table 7 provides a summary of the cost of recyclable waste. Aluminum, PET bottles, and electronic waste are the most popular materials. IWPs leave electronic trash despite high selling prices, possibly due to households' likeliness to hoard this garbage.

The estimated monthly per capita income for each informal garbage collector is also averaged out in Table 7. Using survey data, we determined that the average monthly per capita income was $179.40, considering a daily value of $8.18, and a total of 22 working days per month, considering five days a week. This amount is relatively close to the [25] findings, which determined that the monthly income was $167.31. As of June 2022, the average salary equals 42.2% of the monthly minimum wage in Ecuador ($425) and 24.8% of the monthly cost of a family's grocery basket ($724.4) [36]. Table 8 shows the marketing conditions of the collected waste by the sampled IWPs. First, most IWPs prefer to sell their products directly to recycling companies, followed by intermediate companies, which is surprising, given that it was expected otherwise. However, the size of the recycling companies will influence their acceptance

Table 7
Prices of recyclable materials and expected income according to IWPs per kg.

Type	Mean	SD	Min	Max	Sales Volume (USD/day)
White Paper	$0.41	$0.53	$0.02	$2.75	$1.05
Newspaper	$0.28	$0.32	$0.02	$1.60	$0.20
Cardboard	$0.47	$0.70	$0.05	$3.25	$0.98
Soft Plastic	$0.48	$0.87	$0.08	$3.50	$0.72
Hard Plastic	$0.55	$0.62	$0.03	$4.25	$0.75
PET Bottles	$1.18	$1.83	$0.02	$9.00	$1.29
Iron	$0.77	$1.15	$0.06	$5.00	$0.89
Glass	$0.46	$0.54	$0.01	$2.50	$0.33
Aluminum	$0.90	$2.24	$0.03	$3.22	$1.13
Electronic Waste	$1.19	$1.93	$0.03	$8.75	$0.83
Daily Total income					**$8.18**
Monthly per capita Income					**$179.91**

Table 8
Marketing conditions of collected waste.

Market Conditions	Total (%)	Male (%)	Female (%)
Places IWPs sell their products to:			
Intermediate Concessionaries	25.55	26.99	18.75
Manufacturing Companies	14.96	14.60	16.67
Recycling Companies	50.00	49.56	52.08
Others	9.49	8.85	12.50
Forms they sell their waste			
Pellets	1.32	1.58	0.00
Grinded	2.64	3.16	0.00
As they collect them	86.34	84.74	91.89
Flakes	5.29	5.79	2.70
Others	4.41	4.21	5.41
How they sort their collected plastic waste			
Type of polymer	51.98	49.47	64.10
Purity	9.69	10.64	5.13
Colour	14.10	15.43	7.69
Other (Quality, Brand, Shape)	24.23	24.47	23.08

or not of recyclable waste from IWPs.

More prominent recycling companies typically prefer high volumes rather than the small ones they can obtain from IWPs. Second, IWPs usually deliver their products as they collect them. Third, IWPs prefer to separate their collected plastic waste by polymer type, followed by quality, brand, or shape.

Thirty-nine percent of IWPs believe that the buyers set the price, while 29% and 25% believe the price depends on the quality of collected waste and the offer and demand market (see Fig. 9a). Thirty-three percent of the sampled population prefer to classify their waste, and twenty-seven percent compact it before selling. A surprising 18% of the IWPs population indicate that they clean the waste (maybe to eliminate organic rests), while only 9% wash and dry it (see Fig. 9b).

3.4. Total CF and WF avoided by IWPs

For the calculation, the total CF and WF of 1 kg of each collected waste were obtained with the help of SimaPro 9.1 software, considering that all waste reaches the local landfill. As shown in Table 9, the CF per kg of collected waste is calculated. Almost every waste was found in SimaPro 9 databases, but electronic or electronic waste was unavailable. The CF for electronic waste was obtained from the bibliography. One Belgian Consulting Firm analyzed the impact of electronic waste recycling on CO_2 emissions, finding out that per kg just from the collection, a total of 0.35 kg of CO_2 eq is avoided [37].

According to SimaPro 9.0 databases, waste transportation with diesel-powered garbage trucks produces 0.0657 kg CO2 eq per ton and Km. From the calculations previously shown in Table 6, each IWP collects a total of 13.17 kg, and as a reference, each garbage truck covers between 20 and 37 km daily. Considering 4000 IWPs in the city, and an average of 28.5 km covered per truck daily, the total amount of CF avoided by not using them is 1501.38 tons and Km daily and 98.64 kg of CO2 eq daily.

The transport sector's annual avoided contribution is 36 tons of CO2 eq, and the total avoided CF for the entire informal recycling collection process is 13.90 thousand tons of CO2 eq, as shown in Table 9.

3.5. Formalization potential of informal waste pickers

It was discovered that 95% of IWPs operate their recycling businesses independently (see Table 10); the remaining 5% are cooperative members. When asked what they would do if asked to join a cooperative, only 16% of IWPs responded that they would

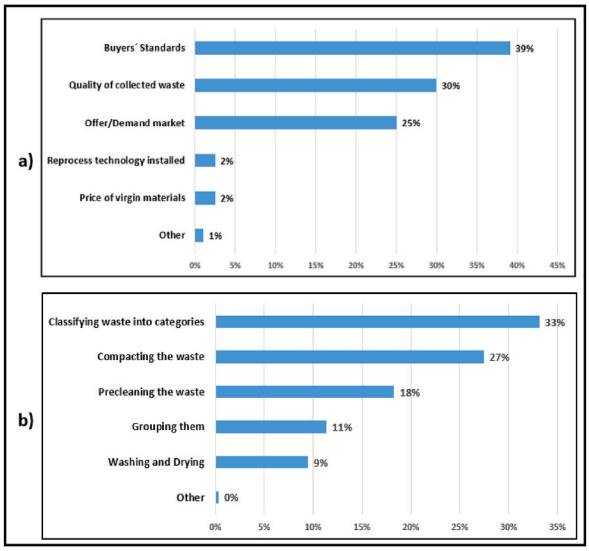

Fig. 9. Price of collected waste: a) External Factors, b) Added value by IWPs.

Photo 1. Evidence of surveyed population by university volunteers.

prefer to do so now. Another 22% stated they could wait to decide whether or not to join until they saw improvement, while the remaining 57% said they would continue working alone. When asked why they wanted to increase their income, the majority (64%) of the 19% of the population already belonged to or would join a cooperative. Prior studies have shown that group efforts can improve the amount of recyclables recovered and the area covered by material recovery, increasing profitability [38].

Conflict avoidance (30%), profit reduction (28%), and being used to working alone (42%) were the top three reasons given by those who said they would prefer to keep working alone. IWPs are, therefore, unlikely to establish a cooperative on their own, though some would do so if someone else started the formalization process. These findings are consistent with formalization research that [38] carried out in Blantyre, Malawi.

Even though the sampled population of IWPs accepted all the statements asked for their formalization with percentages higher than 70%, the most important ones, according to them, to consider formalization were: legalizing the collection (24.4), obtaining training

Table 9
CF avoided due to the avoidance of landfill by IWPs (N = 227).

Type	CF (Kg CO_2 eq/kg waste)	Waste (kg/day/IWP)	Daily avoided CF (kg CO_2 eq/IWP)	Daily total avoided CF (kg CO_2 eq)	Yearly total avoided CF (ton CO_2 eq)
White Paper	1.3400	2.57	3.4438	13,775.20	5027.95
Newspaper	1.3400	0.73	0.9782	3912.80	1428.17
Cardboard	1.7300	2.08	3.5984	14,393.60	5253.66
Soft Plastic	0.1090	1.50	0.1635	654.00	238.71
Hard Plastic	0.1090	1.37	0.1493	597.20	217.99
PET Bottles	0.0767	1.09	0.0836	334.40	122.06
Iron	0.6970	1.16	0.8085	3234.00	1180.41
Glass	0.0044	0.72	0.0032	12.80	4.67
Aluminum	0.0213	1.25	0.0266	106.44	38.85
Electronic Waste	0.3469	0.70	0.2428	971.31	354,53
		13.17	**9.4979**	**37,991.60**	**13,866.93**

Table 10
Interests in working as a cooperative (left) and reasons (right).

Interest to work as a Group	Total (%)	Reason	Total (%)
I already belong to one	9 (3.96)	Increase my income	30 (63.83)
I'd like to join immediately	38 (16.44)	Free transport	17 (36.17)
I'd like to continue alone	130 (57.27)	Used to work alone	75 (41.67)
I'll wait for the evolution	50 (22.03)	To Prevent Conflict	54 (30.00)
		It reduces profit	51 (28.33)

and loans (24.7, 24.8), raising the awareness of the public of their importance (24.12), increasing the recycling facilities (24.10), and creating markets where they can sell their waste (24.6) (see Table 11).

Additionally, when they were asked to establish the importance of different threats they face during the execution of their work, it was also found that all threats were significant, with all percentages higher than 70%. Nevertheless, considering just those over 80% acceptance rate, the main threats were: lack of tools (25.1), lack of government support, lack of public awareness, lack of transport equipment, and most importantly, lack of markets (see Table 11).

4. Discussion

The informal collection is a green substitute for chains of separation and recovery because it adheres to the sustainability axes (environmental, social, and economic considerations) that promote eco-development, eco-efficiency, and the emergence of eco-businesses, including informal ones [39,40]. Avoiding the transportation and final disposition of these collected materials have environmental benefits. However, the after-recycling processes must be analyzed since they produce environmental impacts.

Our results on objectives two and four serve as the basis for analyzing possible recycling scenarios and choosing the best one according to the difference between avoided carbon footprint from the collection process and the one generated by the recycling process. The development of inverse logistics scenarios, which include the data acquired during the present work, together with information previously obtained from waste transfer stations [41], and the location of the recycling facilities is possible with the help of some statistical tools to make predictions, such as Kernel Adaptive Filtering Framework [42] for the pick-up logistics, together with city routes image analysis through deep-learning based approaches [43].

Table 11
IWPs statement acceptance for formalization (Q24) and challenges (Q25).

Question 24	Average	Question 25	Average
24.1	72,16%	**25.1**	80,53%
24.2	75,07%	**25.2**	77,62%
24.3	73,30%	**25.3**	77,53%
24.4	81,06%	**25.4**	78,50%
24.5	77,53%	**25.5**	82,11%
24.6	84,76%	**25.6**	83,00%
24.7	81,50%	**25.7**	80,79%
24.8	81,32%	**25.8**	74,63%
24.9	80,00%	**25.9**	75,68%
24.10	82,03%	**25.10**	80,00%
24.11	79,47%	**25.11**	80,88%
24.12	81,67%		

In this matter, the avoided carbon footprint due to the informal collection process can help decision-makers better understand this activity's environmental sustainability since this indicator is well-known and easier to understand than other environmental categories in the life cycle assessment methodology. In general, informal waste collectors and the informal recycling industry will be crucial components of the circular economy in the global south in any plausible future scenario [11,44]. Integrating the current unofficial recycling schemes into the MSWM can significantly impact the livelihoods of IWPs, society, and the environment [45]. However, they are still seen as nasty, drug-using outlaws despite their importance to the environment and economy, and they must deal with exploitation and unfair power dynamics with the rest of the waste management hierarchy [44,46].

Consequently, finding strategies for successful, scalable, and sustainable collaboration with the informal recycling sector is crucial since waste management and recycling in the global south's low- and middle-income nations are often highly informal. In this matter, the results found for objectives one and four helped determine their current social conditions and their perception of the challenges and barriers preventing them from formalizing their services.

Previous research has found different methods for formalizing IWPs, such as their involvement in organizations, cooperatives, or micro-small enterprises and coming to be contracted as individuals by the formal municipal waste management sector [23]. Associations and cooperatives of garbage collectors have become much more visible in Brazil, and public policies for their formalization have been developed at many levels of government, including the national, sub-national, and local levels [47]. In Colombia, particularly Bogota, the integration of IWPs is done by upgrading them to private suppliers during a time-lapse of 5-years, with the final objective of their qualification to compete in future bidding official processes for collection services.

IWPs' formalization presents several advantages in the literature. From a total of 45 reviewed papers [48], concluded that the formalization of waste pickers has many advantages, including lowering poverty, preventing child labor, addressing gender disparity, and increasing the respect for waste pickers. Additional benefits include obtaining material resources, economies of scale, and political rights that they would never be able to gain on their own. They can pool their resources to buy or rent cleaning and storage facilities by making an ally, enabling bulk sales, possibly larger incomes, and a stronger negotiating position [49]. Participating in a cooperative also could give them access to several insurance options and government-sponsored protection [50].

5. Conclusion

The current research made the case that recyclable waste picking is an essential source of income for the poor and marginalized sectors of the population and that informal waste pickers contribute significantly to cities, particularly in the pursuit of sustainable development, allowing to address numerous difficulties that are penetrating the social, environmental, and economic spheres alike.

In many circumstances, integrating waste pickers into waste management and recycling programs can be socially and environmentally desirable. Municipalities must interact with waste pickers as prospective partners, and decision-makers must see them as assets. However, public attitudes and policies are still primarily based on false assumptions about waste pickers' contributions to the environment, public health, and urban economies.

This research used survey-based interviews with different informal waste pickers to learn more about Guayaquil's informal waste collectors and how their job affects the environment by calculating the carbon footprint avoided due to the collection of organic and inert materials that otherwise would end up buried in the local landfill.

Even though this study presents some significant results, some limitations must be addressed. First, the total waste mass collected was quantified through range values reported by the IWPs. However, these values could have some bias as they do not have scales, and most of their information on the mass comes from waste transfer stations or recycling facilities once they have sold them. Second, the total mass collected and the carbon footprint avoided by the informal waste pickers in the city have been made on the assumption of a population of 4000 IWPs. However, to this date, there are no official records from any government organization on the total quantity of IWPs in the city other than those reported on other communication alternatives, such as newspapers.

Future studies could concentrate on conducting in-person interviews with informal waste pickers to understand better their lifestyles, working circumstances, perspectives, and expectations. Another intriguing subject for future research would be to clarify the viewpoint of IWPs' customers, such as the waste transfer stations or recycling facilities. In addition, a database update would provide the foundation for a regression analysis between recycled material and sociodemographic factors and a review of the economic viability of the formalization into a cooperative process. Finally, an inverse logistic model should be proposed to improve the informal waste-picking sector's current collection rates and working conditions.

In summary, this paper quantifies the importance of the work done by informal waste pickers in the city of Guayaquil and their contributions to the city's society, economy, and environment. However, this profession is one of the most hazardous and insufficiently rewarded activities, left to a certain marginal and impoverished population sector. Ignoring the difficulties IWPs face in the formal waste management systems inhibits social inclusion and environmental sustainability in cities without a differentiated waste separation system and a lack of resources in the local landfills to separate recyclable materials.

Author contribution statement

J. Hidalgo-Crespo: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data;

Contributed reagents, materials, analysis tools or data; Wrote the paper. J.L. Amaya-Rivas: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper. Inês Ribeiro: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper. M. Soto: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper. Andreas Riel: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper. Peggy Zwolinski: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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